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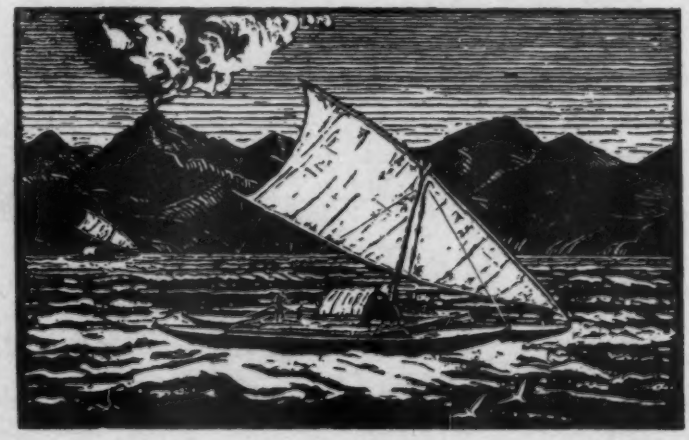
PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION



IN THIS ISSUE: Macdonald and Wentworth — *Kona Earthquake of August 21, 1951* ● Li — Acer *in Formosa and Liukiu Islands* ● Barnard — *A New Species of Ampbipod from Lower California* ● Demond — *Nassariidae of the West Coast of North America* ● Grimm — *Iodine Content of Marine Algae* ● NEWS NOTES ● INDEX

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CONTENTS

PAGE

The Kona Earthquake of August 21, 1951, and Its Aftershocks. GORDON A. MACDONALD AND CHESTER K. WENTWORTH 269

The Genus Acer *(Maples) in Formosa and the Liukiu (Ryukyu) Islands.* HUI-LIN LI 288

A New Species of Amphipod from Lower California (Genus Eriopisa). J. LAURENS BARNARD 295

The Nassariidae of the West Coast of North America between Cape San Lucas, Lower California, and Cape Flattery, Washington. JOAN DEMOND . . . 300

Iodine Content of Some Marine Algae. MADELON R. GRIMM 318

NEWS NOTES 324

INDEX 325

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The Kona Earthquake of August 21, 1951, and Its Aftershocks[1]

GORDON A. MACDONALD and CHESTER K. WENTWORTH[2]

INTRODUCTION

AT THREE MINUTES before one o'clock on the morning of August 21, 1951, the southwestern part of the island of Hawaii was shaken by the strongest earthquake recorded there since 1868. The earthquake of August 21 was felt strongly all over the island of Hawaii, weakly on the island of Maui, and in Honolulu, 180 miles away from its origin. Extensive damage resulted in the central Kona district, and lesser damage extended all the way to Naalehu, about 38 miles from the epicenter. The major earthquake was followed by a large number of aftershocks which, although they did little damage, kept the populace of Kona uneasy for several weeks.

A detailed study of the earthquake was immediately undertaken by the staff of the Hawaiian Volcano Observatory. No sharp division of labors existed, but for the most part Macdonald was responsible for the general and instrumental phases of the investigation and Wentworth for the detailed studies of damage, such as that affecting water tanks, stone walls, and gravestones.

Acknowledgements: It is impossible to mention by name all the persons who aided the investigation by contributing observations on the earthquake itself and data on resulting damage. To all these we extend our sincere thanks. Special thanks are due Howard M. Tatsuno, seismograph operator at Konawaena High School near the epicentral area; Sister Mary Thecla, seismograph operator at St. Joseph's School in Hilo; Mrs. Alfred E. Hansen at Naalehu, Allan P. Johnston of Kapapala, and Nancy R. Wallace of Kealakekua, who contributed descriptive reports of many of the aftershocks. Roland E. White, of the Honolulu Magnetic Observatory, U. S. Coast and Geodetic Survey, kindly sent copies of the seismograms of the major earthquake as recorded at Barbers Point, on Oahu. Commander C. A. George, of the Coast and Geodetic Survey, supplied copies of the tide gauge records from Honolulu and Hilo harbors, showing the small tsunami that followed the earthquake. Many persons supplied information on damaged water tanks. Among these Mark Sutherland, Principal of Konawaena School, John Iwane, Extension Service, University of Hawaii, and Masuoka Nagai, of Captain Cook Coffee Company, were especially helpful.

NARRATIVE

Most residents of the island of Hawaii were in bed when the earthquake struck. Nearly everyone in the Kona and Kau districts was awakened, and most people rushed outdoors. Persons in the area near the epicenter reported that the initial movement was largely up and down, with some swaying in an east-west direction, increasing in intensity and giving way to what appeared to be a vortical motion. Noise during the earthquake was intense as doors and windows rattled,

[1] Publication authorized by the Director, U. S. Geological Survey. Manuscript received May 7, 1952.

[2] Director and Geologist, respectively, Hawaiian Volcano Observatory, Hawaii National Park, Hawaii.

dishes and furniture toppled to the floor, water tanks collapsed, and rocks rolled down from stone walls and banks. A few persons who were awake at the time the earthquake occurred reported that the quake was immediately preceded by a dull roar seeming to come from the ground. Shaking is reported to have been nearly continuous for an hour or more after the major shock.

Macdonald was driving through Naalehu, 36 miles from the epicenter, when the earthquake occurred. The car swerved violently, as though it had struck a mudhole. Immediately afterward branches started to snap from trees overhead and fall on the pavement.

Within a matter of moments several houses, churches, and a school building were badly damaged, many other houses slightly damaged, about 200 water tanks destroyed, many miles of stone wall thrown down, roads partly blocked by rock slides, road pavement and shoulders badly cracked, cemeteries damaged, telephone communication and electric power supplies disrupted. Fortunately, only two persons were injured, and they not seriously.

Damage extended for more than 50 miles along the highway that encircles the island, from Holualoa on the north to Honuapo on the southeast. Damage was greatest along the 10-mile stretch from the village of Captain Cook to Hookena (Fig. 1), but as far away as Naalehu many dishes were thrown to the floor in homes, groceries and liquor bottles thrown from shelves in stores, and one house was shifted several inches on its foundations. A few objects were toppled from shelves, pavements were cracked, and numerous landslides started in the vicinity of Kilauea Caldera, 45 miles from the epicenter.

At Napoopoo the ocean was observed withdrawing from shore, and most of the inhabitants of the village were hurriedly evacuated to higher ground until the possibility of a destructive tsunami was past.

Two small fires broke out. One was at Kaimalino, 0.3 mile south of Kealia, where kerosene, spilled in a kerosene-powered refrigerator, caught fire. The other was in Naalehu, where the earthquake upset a kerosene lamp. Both fires were quickly extinguished.

Bright flashes of white light at the time of the major earthquake were reported by persons at Naalehu and Pahala. These persons believe the flashes were not the result of electrical short circuits. Peculiar lights have occasionally been reported during other strong earthquakes.

During the night of August 21–22 persons in the central Kona area reported a distinct odor of hydrogen sulfide, apparently occurring in intermittent waves. The source of this odor is not known. No increase of fuming was observed at the vents of the 1950 eruption on the southwest rift of Mauna Loa.

Aftershocks in great number followed the major earthquake. The seismograph at Konawaena School was badly damaged by the first quake, so the total number of aftershocks will never be known. However, Mrs. H. Masuhara, at Keei, counted 109 felt earthquakes between the principal shock and nine o'clock the next morning. The Konawaena seismograph was repaired and restored to operation at 15:15 on August 23. It recorded 90 earthquakes during the next 24 hours and 494 earthquakes up to midnight on August 31. Most of these, of course, were too small to be felt, even close to the epicenter. Strong aftershocks occurred at 01:28, 09:56, 10:12, 18:32, and 22:48 (Hawaiian Standard time) on August 21, and at 17:15 on August 22. Only slightly less strong were those at 02:14 and 06:28 on August 22. Because of continued earthquakes, graduation ceremonies at Konawaena School on August 22 were held outdoors instead of in the auditorium.

INSTRUMENTAL DATA

The major earthquake dismantled all seismographs on the island of Hawaii. All but the Bosch-Omori seismograph in the Whitney Laboratory on the northeast rim of Kilauea

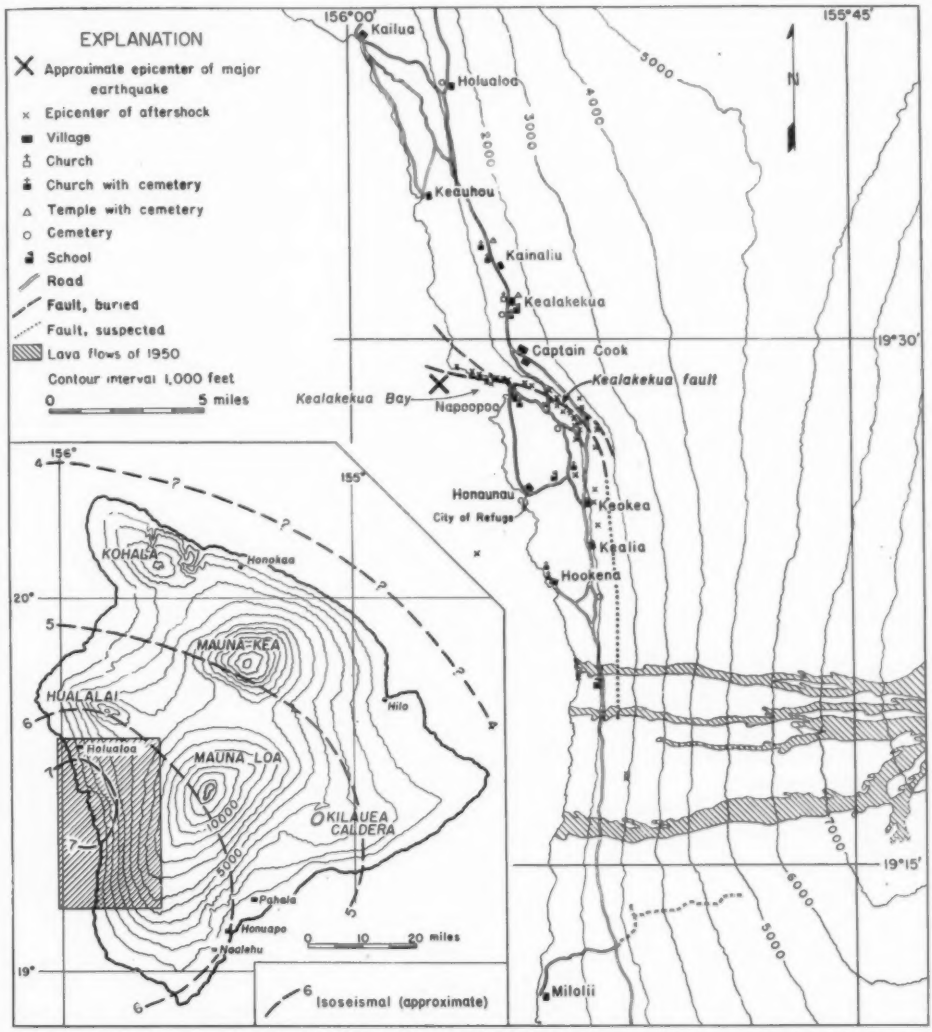

FIG. 1. Map of the central Kona district showing the location of places mentioned in the text and the approximate locations of the epicenters of the major earthquake of August 21, 1951, and of the aftershocks for which reasonably good locations were obtained. The inset map of the island of Hawaii shows the location of the area (shaded) covered by the other map and the approximate position of the isoseismal lines for the major earthquake.

Caldera were dismantled by the preliminary waves. Precise time control and, consequently, the precise time of arrival of the first waves are lacking on the Kona and Hilo instruments. As a result, instrumental data are inadequate for the close location of the focus of the earthquake. The duration of the preliminary waves on the north-south component of the Bosch-Omori instrument was 9.5 seconds, corresponding with a distance of approximately 47 miles from the Whitney Laboratory to the origin of the quake.

John C. Forbes, instrument maker at the Volcano Observatory, repaired the minor

damage to the Bosch-Omori seismograph and put it back in operation at 01:24, 27 minutes after the first earthquake started. At that time the instrument was recording the long waves of a large earthquake. The period of these waves ranged from about 6 to 8 seconds and averaged approximately 6.7 seconds. Their maximum double amplitude was 67 millimeters, corresponding to a theoretical ground displacement of approximately 0.5 millimeter. These waves continued with gradually decreasing amplitude until 03:20. Because no other earthquake at an appropriate time was observed by more distant stations, it is believed that these long-period waves were the surface waves of the major Kona earthquake.

The time of origin of the major earthquake is given in the notice of preliminary determination of epicenter issued by the U. S. Coast and Geodetic Survey as $00^h56^m57.5^s$ Hawaiian Standard time ($10^h56^m57.5^s$ Greenwich Civil time). The time of beginning of registration of the preliminary waves at the Whitney Laboratory at Kilauea was $00^h57^m09.5^s$ Hawaiian Standard time.

The direction of the first ground movement at Kilauea Caldera was east-southeast and up, that at the Mauna Loa station was east-northeast, and that at the Kealakekua station was east-northeast. At the Kealakekua station the north-south component was only slightly damaged, but on the east-west component the suspensions were broken and the weight dropped on the floor 2 feet west of the pier.

The Kona seismograph, at Konawaena School (Fig. 1), was restored to operation at 15:15 on August 23. Previous to that time, location of the points of origin of the aftershocks on an instrumental basis was uncertain because of the very short base of the triangle formed by the intersection of lines from the earthquake foci to the other stations. Earthquakes after that time are fairly well located because of the control given by the Kealakekua seismograph. Most of these were located by means of data from four stations: Kealakekua, Mauna Loa, Hilo, and Whitney (Kilauea).

Locations of the epicenters of aftershocks which occurred after 15:15 on August 23 with serial number greater than 190 are shown in Figure 1. Thirty-three such aftershocks have been located with small probable error. Most of them fall on or close to a fault that runs out to sea in a west-northwesterly direction along the northern edge of Kealakekua Bay. The existence of this fault, partly buried by later lava flows, has been recognized for many years (Dana, 1890: 30; Stearns and Macdonald, 1946: 37, pl. 1). At its eastern end it bends southward, and the writers have suspected that the abnormally steep lower western slope of Mauna Loa inland from the highway for 15 miles or more south of Captain Cook is a fault scarp deeply buried by later lava flows. An interesting partial confirmation of this theory is furnished by the location of the epicenters of several aftershocks along this line (Fig. 1).

The frequency of aftershocks decreased rapidly from August 23 to September 4. As is shown in Figure 2, the average frequency then decreased very slowly until the end of September. No figure is available for September 7 because of mechanical failure in the recorder at the Kealakekua station. The apparent depth of origin of the aftershocks ranged from 3 to 12 miles, most being about 6 or 7 miles. No progressive change of depth with passage of time is apparent.

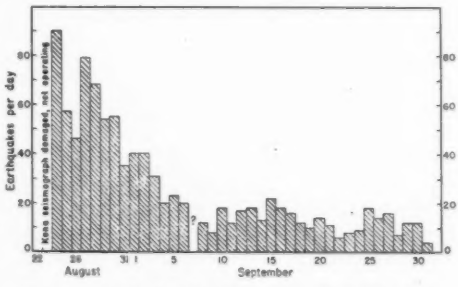

FIG. 2. Graph showing frequency of aftershocks to the end of September, 1951.

Altogether, from the time it was put back in operation until the end of August, the Kealakekua seismograph recorded 494 earthquakes, and until the end of September 965 earthquakes. Nearly all of these are regarded as aftershocks of the big earthquake of August 21. Most were too small and shallow-seated to be recorded at the other stations, hence their foci could not be closely located. It appears certain, however, that most originated along the Kealakekua fault at the northern edge of the Kealakekua embayment.

EFFECTS OF THE EARTHQUAKE

Description of Terrane

The epicentral area lies on the western slope of Mauna Loa, a few miles south of the surficial boundary between Mauna Loa and Hualalai Volcanoes. It is transversed from north to south at altitudes of 1,000 to 1,300 feet above sea level by the main highway, from which roads lead to the shore at Napoopoo, Honaunau, Hookena, and Milolii (Fig. 1). In the vicinity of the highway the average slope of the land surface is about 10 degrees, which is several degrees steeper than the average for Mauna Loa slopes in general. Above an altitude of 5,000 feet the average slope decreases to about 7 degrees. The steepness of the lower part of the slope is believed to result from an ancient fault scarp deeply buried by more recent lava flows.

In the area within 6 miles south of Napoopoo the steep zone is narrower and more sharply defined than farther south, and west of it the slope again flattens toward the sea. Three miles east-southeast of Napoopoo the steep zone turns sharply northwestward and becomes even steeper, taking on the unmistakable characteristics of a fault scarp mantled by more recent lava flows. This scarp forms the northern boundary of Kealakekua Bay, and there the older lava beds in the scarp are not mantled by later flows.

The steep seaward slope results in a distinct asymmetry of the terrane, which asymmetry of necessity extends to nearly all structures on the terrane. Buildings rest on foundations that are high on one side and low on the other. Roads in many places rest on a cut on one side and fill on the other, or on a fill which is shallow on one side and deep on the other. Stone walls parallel to the coast have one sloping side shorter than the other. All of this results in a lesser degree of stability than in structures built on level terranes, and in a favored direction of unstability. Partly because of the higher foundations and deeper fills on the seaward side and partly because of the continuous effect of gravity, structures tended to move downhill during the earthquake regardless of the direction of the actual shaking. This effect must be considered in using the direction of displacement of objects as a means of locating the epicenter.

Rock Slides

Many small rock slides in highway cuts were caused by the earthquake. Most of them came from cuts on the inland side of the highway, probably largely because the cuts were higher on that side. Most of the slides were small, bringing down blocks less than 2 feet across. These caused little damage and were easily removed. A few larger slides brought down large blocks weighing several tons, the removal of which required the use of bulldozers or other heavy equipment. The large slide farthest from the epicenter occurred at a high roadcut just west of Honuapo, 40 miles from the epicenter. Small slides and rock falls in road cuts extended all the way to Kilauea Caldera, 44 miles from the epicenter. Many small rock avalanches took place in Halemaumau Crater during and for several days after the earthquake.

A large part of the damage to road cuts did not, strictly speaking, result from sliding of the materials. Most of it was merely a fraying of the banks by the rolling down of loose or semiloose material. Few of the highway cuts exceeded 5 feet in height, and few

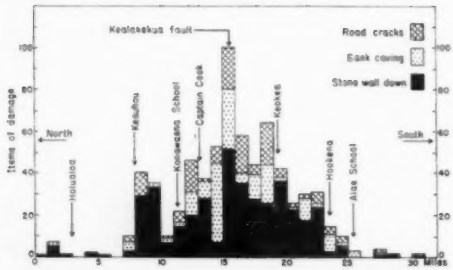

FIG. 3. Diagram showing the frequency distribution of three of the principal types of earthquake damage along the main highway. The arrows indicate the position on the highway of some villages and other features. Note the centering of damage close to the Kealakekua fault.

were dressed back to any approximation to an equilibrium slope. The earthquake of August 21 greatly exceeded in size any previous quake in the affected area since the road cuts were made, and shaking during the earthquake merely dislodged much of the loose material and allowed it to roll down onto the road.

The distribution of abundance of rock slides in road cuts is shown in Figure 3, in which it is represented by the portion of the columns labeled "bank caving." Like the other damage shown in the graph, it was greatest in the immediate vicinity of the Kealakekua fault, inland from and a little south of Kealakekua Bay.

Many large slides took place on the fault scarp at the northern edge of Kealakekua Bay. The slides caused a disturbance of the water of the bay just after the earthquake, and many residents of the coastal village of Napoopoo fled inland, fearing a big tsunami. Slides continued on the Kealakekua cliff for several days after the earthquake, sending up clouds of yellowish-brown dust, leaving fresh scars on the cliff face, and building talus fans at the foot of the cliff.

Less numerous and smaller slides also occurred along the cliff just inland from the village of Hookena Beach. The cliff at Hookena is believed to be an ancient fault scarp, mantled by lava flows from the upper slopes of Mauna Loa during prehistoric times. Many fragments of the lava veneer were shaken down during the earthquake.

Tsunami

Despite early reports to the contrary, there is no doubt that the earthquake was accompanied by a small tsunami, or "tidal wave." At Napoopoo wharf the water was observed to withdraw from shore. The tide was low at the time. Withdrawal of the water lowered the level to about 4 feet below normal low-tide level. Immediately afterward the water returned shoreward, and the level rose about 2 feet above low-tide level.

At Milolii, Eugene Kaupiko reported that a few minutes after the earthquake, which he felt while in a canoe anchored offshore, the water receded from shore, revealing the sea bottom as far out as the edge of the wharf. This represents a lowering of the water level of about 3 feet. After the withdrawal the water returned shoreward, causing a rise of the water level 3 or 4 feet above normal low water and floating away a canoe that had been drawn up on the beach about 2.5 feet above high-tide level. One large fall and rise of the water level appears to have been followed by many small oscillations.

At Honaunau, between Napoopoo and Milolii, Eli Cooper, caretaker of the City of Refuge, went down to the water's edge a few minutes after the earthquake. At that time he could see no signs of disturbance of the water, but a small tsunami could have occurred between the time of the earthquake and his arrival at the strand. At Hookena no tsunami was observed, and there was none large enough to flood the floor of the dock, about 4 feet above normal water level. However, it cannot be said definitely that no small tsunami occurred there.

The Honolulu tide gauge record shows a distinct oscillatory disturbance of the water starting at approximately 01:35, about 38 minutes after the earthquake. Seven or more oscillations are detectable, with an average

period of about 14 minutes, reaching an amplitude from crest to trough of 3.6 inches. This undoubtedly is the record of a seiche set up in Honolulu harbor by the tsunami. Using the time of beginning of the disturbance at Honolulu as that of arrival of the tsunami, the average speed of travel of the tsunami from the epicenter to Honolulu was approximately 284 miles an hour. The time of beginning of the disturbance at Honolulu corresponds well with the calculated theoretical arrival time of a tsunami caused by the Kona earthquake, so there can be little doubt the disturbance was of that origin. A similar disturbance is shown on the record of the Hilo tide gauge. The time of beginning of the disturbance at Hilo is less definite, but appears to have been about 02:38. This corresponds with a much slower average speed of travel of the tsunami, of about 78 miles an hour, as the waves were refracted around the island in comparatively shallow water.

Damage to Buildings

Shortly after the earthquake the Kona police estimated that about 200 houses in the area had suffered some degree of damage. Most houses in the area near the epicenter are of frame construction, set on knee-braced timber underpinning. Such supports proved capable of undergoing the shaking and distortion caused by the earthquake without serious damage. Most of the damage was minor and quickly repaired. Some houses shifted from a fraction of an inch to 3 or 4 inches on their foundations. Many were sufficiently twisted out of line to make it difficult or impossible to close windows and doors. In nearly all houses dishes and other objects were thrown from shelves. Only the more seriously damaged structures are enumerated here.

At Kaimalino, 0.3 mile south of Kealia (Fig. 1), a shop building collapsed. This building was placed on timber supports level with the highway in front but 6 feet above ground level in back, without adequate cross bracing.

FIG. 4. Overthrown shop building at Kaimalino, from the south.

Failure of the underpinning allowed the building to tilt backward and slump to the ground (Fig. 4). A similar situation was found at Keokea, 1.2 miles north of Kealia, where a service station building slumped downhill away from the highway and partly collapsed.

In the Kahauloa area, about 1.7 miles east of Napoopoo village, the walls of a store partly collapsed as a result of distortion of the building caused by shifting on its foundation. The warehouse of another store was badly damaged.

At Hookena Beach two old frame houses were destroyed. One, which had been occupied briefly in 1889 by Robert Louis Stevenson, fell when its timber underpinning failed, and collapsed. The other also was dropped onto the ground by collapse of its underpinning. It appears to have fallen almost straight downward. The building was somewhat twisted, but not otherwise seriously damaged. At Kealia and at Kiilae, about 0.4 mile south of Kealia, two other frame houses were badly damaged by collapse of their timber underpinning. All of these cases of collapse of frame houses appear to have been caused by inadequate bracing or poor materials in the underpinning, in some instances probably aggravated by insecure footings.

The cases of structural damage most distant from the epicenter occurred at Naalehu, 36 miles southeast of Napoopoo, where wallboard in a restaurant was cracked, and one

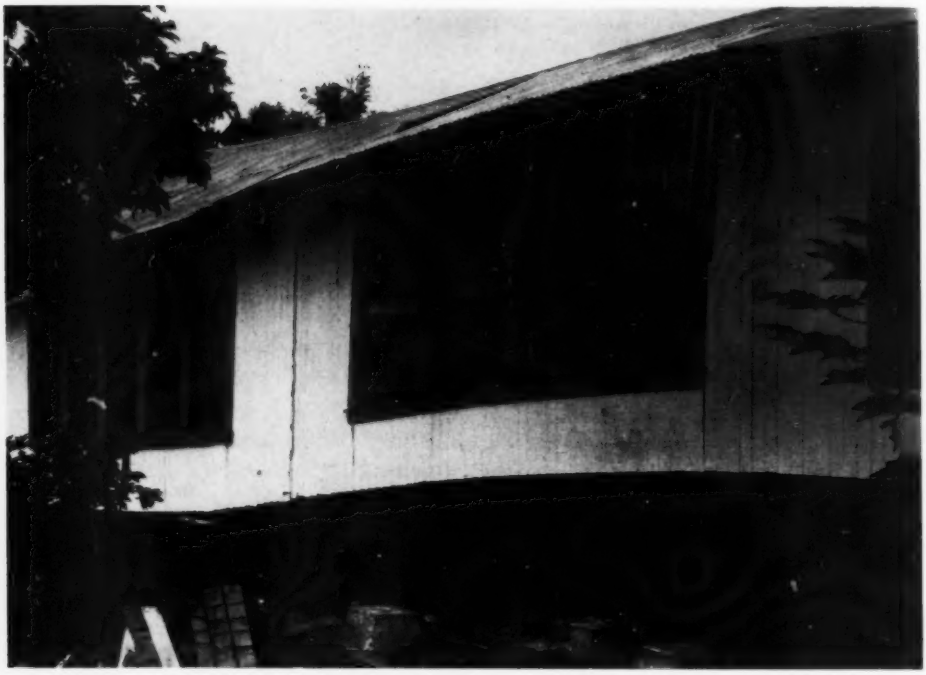

FIG. 5. Central portion of Honaunau School, from the southwest. All but the south end of this building was let down and moved westward owing to inadequate bracing of the underpinning in an east-west direction transverse to the longer dimension of the building.

house was moved several inches on its foundation.

A striking example of the effect of poorly designed underpinning is furnished by the Honaunau School. This was a long, narrow frame building placed with its length parallel to the contour of the ground surface. The front of the building was about 3 feet and the back about 10 feet above ground level. It was supported on timber posts. The posts and knee bracing parallel to the length of the building were entirely adequate, but there was comparatively little bracing parallel to the shorter direction of the building, and some of this was fastened not to joists but to floor boards. As a result, the underpinning was deficient in stiffness in the direction parallel to the ground slope. The direction of shaking during the earthquake was nearly parallel to this direction of weakness in the structure, and the swaying of the structure caused the underpinning to fail in part and to allow the building to slump downhill onto the ground (Fig. 5). The building is considered a total loss.

There were several church buildings with masonry walls in the area near the epicenter. Most of these suffered some damage, and some were very seriously damaged. The masonry consists of fragments of lava rock laid with a mortar made by calcining coral limestone. In some there was very little mortar in the inside parts of the wall. Most of the buildings were more than 95 years old.

The Central Kona Church at Kealakekua suffered cracking of the interior plaster on the east and west walls, but the masonry showed little or no cracking. At the back of the church is a small lean-to addition, the roof of which is supported by beams with

one end set into niches in the wall of the main building. During the earthquake there was enough differential movement of the two portions of the building to pull the beams out of their supporting niches and allow the roof of the addition to drop a few inches. At the front of the church is a tower covered with exterior plaster. The tower and main church building are essentially separate structures and appear to have moved independently during the earthquake. The plaster of the tower was badly cracked.

St. Paul's Church at Honalo, 1.9 miles north of Kealakekua, suffered severe cracking of the masonry in both the main building and the rectory. Kahikolu Church, at Napoopoo, suffered surprisingly little damage. The lintels and interior plaster showed some cracking, but the masonry was unharmed.

The Protestant church at Hookena Beach was badly damaged. The building consisted of masonry walls and a sheet-iron roof, supported on heavy handhewn beams which in turn were supported by east-west beams resting in niches on the upper edge of the front and back walls. During the earthquake nearly the whole front (west) wall was thrown out, some debris being as much as 25 feet from the building (Fig. 6). The other walls were not appreciably damaged, even the interior plaster being almost uncracked. It appears possible that during the quake the roof may have tended to move as a separate unit from the rest of the structure and, by its tendency to lag behind during the initial violent eastward movement of the ground, may have pushed out the front wall.

FIG. 6. West end of Pukaana Church at Hookena Beach showing complete demolition of masonry wall of this 100-year-old structure. Much of the debris was cleared away soon after the earthquake. No nearly comparable damage to this building is known to have taken place during the century since it was built.

FIG. 7. Catholic Church 0.6 mile north of Hookena Beach, from the northwest. The east end of this church was similarly thrown down and outward, to the east. The near corner and the corresponding corner of the small building, already without a roof, suggest displacement most markedly to the northwest, in the general direction of the epicenter.

Similarly, a small stone building nearby, which had long been without a roof as is shown by trees growing within the walls, had both its end walls thrown outward, to west and east, while the side walls remain standing though somewhat cracked.

The Catholic church 0.6 mile north of Hookena Beach was very heavily damaged. The upper portions of both the east and west walls were thrown down (Fig. 7), and the interior plaster on all walls was badly cracked. However, the walls were built merely of loose stones laid together without mortar between them except close to the faces, where the interior and exterior plaster had penetrated a short distance. Considering the type of

construction, probably the most surprising feature is that the building had not collapsed previously in one of the strong earthquakes which occur in Kona every few years.

The lessons to be learned from the structural damage caused by the earthquake are those which have been taught by many strong earthquakes elsewhere. A large proportion of the damage results from poor construction or from poor or inappropriate materials. Unreinforced masonry structures are inadvisable in any area subject to strong earthquakes. Footings should be firm, and construction materials, particularly the underpinning, should be sound. Cross bracing, particularly of underpinning, should be adequate in all directions. The best insurance against earthquake damage is good construction.

Damage to Water Tanks

Practically all dwellings in the Kona area are equipped with water tanks for storage of rain caught on the roof. Nearly all these tanks were of wooden stave construction. A large number of these round, tub-type tanks were destroyed or damaged by the earthquake.

The few metal and masonry tanks were undamaged. Because of their importance, not only in Kona but in many Hawaiian communities, a special study of damage to these tanks has been undertaken. The results will be published elsewhere. Only a brief summary is given here.

Altogether, approximately 200 tanks of a total of more than 1,000 in the heavily shaken area were damaged or destroyed by the earthquake. Tank damage extended from Keauhou on the north to Milolii on the south and was most severe in the area from Captain Cook to Hookena. Tanks showed all degrees of failure, from the development of slight leaks to complete collapse. A few tanks may, at least in part, have been pushed over by neighboring structures. Thus, the tank at the southern end of the Honaunau School building (Fig. 8) may have been partly pushed westward by the collapse of the adjacent

FIG. 8. Demolished tank west of the south end of Honaunau School, footings on which the tank formerly stood, and part of the school building, from the southwest.

building, to which it was connected by a rigid wooden down-spout. However, most of the damaged tanks appear to have failed because of their own behavior during the earthquake. The commonest features contributing to tank failure appear to have been poor footings and inadequate cross bracing of the underpinning.

Damage to Stone Walls

The loose stone walls characteristic of the Kona area were extensively damaged by the earthquake. The principal damage was in the area between Keauhou, 3.5 miles north of Kealakekua, and Pahoehoe, 3 miles south of Hookena (Fig. 1). However, isolated instances of wall derangement were observed as far north as Honokahau, 16 miles north of the epicentral area, and Naalehu, 36 miles southeast. The distribution of damage to walls is shown graphically in Figure 3. Many miles of wall required rebuilding. Since the cost of contract rebuilding is approximately a dollar a yard, the total monetary loss from the destruction of walls is considerable.

Most of the stone walls in the area consist of irregular fragments of clinkery aa lava less than a foot across. A few walls have bases of blocks a foot or more long reaching half-

way or more through the wall, and, especially in the older walls, occasional slabs are laid partly or entirely through the wall to help tie it together. Because of the rough, irregular surfaces of the fragments it is possible to build them into a nearly vertical wall 3 or 4 feet high and only about 30 inches thick at the base. Such walls stand well under ordinary conditions, but, because of the shortness of the bonding surfaces of adjacent blocks, they are rather unstable under any joggling, such as by earthquakes. The earthquake of August 21 caused extensive shaking down of the walls. The commonest type of damage was a slumping of the upper part of the downslope face of the wall, the fragments rolling down and out a short distance from the base of the wall. Such damage was especially common on the north-south trending walls and at high places on the walls. In a few instances, walls on nearly level ground were dislodged almost equally in both directions, but the failure was preponderantly on the west side of the walls, and the material from the walls was displaced westward.

Some of the westward displacement of material probably resulted from the tendency of the loose material composing the wall to lag behind during the initial strong eastward movement of the ground. However, a large proportion, perhaps most, of the failures of the walls on their west side undoubtedly resulted from the fact that, because of the general westward slope of the ground, the west side of the wall was higher and usually steeper than the east side, and there was a tendency for materials to shift downslope under the influence of gravity.

Well-built walls were surprisingly resistant to earthquake damage. Thus, the wall along the landward side of the highway from Honaunau to Napoopoo, built of carefully placed rectangular blocks of lava, was almost wholly undamaged despite its location very close to the epicenter. Likewise, in other parts of the epicentral area, older walls in which slabs extending through a large portion of the wall had been used to tie the wall together showed comparatively little damage.

At the ancient City of Refuge at Honaunau, about 20 feet of the seaward side of the main outer wall of the enclosure collapsed. It is interesting to note that damage was restricted to a reconstructed portion of the wall, whereas the remaining portions of the original enclosure wall and the walls of the heiau platforms were undamaged. Homer Hayes, a close student of the City of Refuge, has made the highly plausible suggestion that the peculiar construction of the ancient walls, in which occasional broad slabs extend entirely or largely through the wall and sometimes bridge open spaces beneath, is responsible for the greater resistance to earthquakes of the old portions of the wall.

Damage to Roads

Damage to paved roads was of three general sorts: (1) cracking of pavement, (2) cracking and slumping of shoulders and separation of shoulders from pavement, and (3) collapse of road cuts, causing partial obstruction of the road. The latter has already been discussed under the heading "Rock Slides." Minor cracking of shoulders occurred over an area extending about 10 miles north and 12 miles south of the approximate epicenter, and a few cracks were formed as far away as the northeast side of Kilauea Caldera, 47 miles from the epicenter. However, extensive pavement cracking and slumping were restricted to the area between Captain Cook and Hookena. The distribution of cracks in the road is shown in Figure 3.

Observed cracking or slumping of the pavement or shoulders was entirely restricted to portions of the road on fills. In building the road, some gullies were crossed by laying in a rock fill having a batter, or departure from vertical, of less than 1 in 4, filling with fine material, and laying asphalt pavement across the top. Such fills were insufficiently stable to withstand the shaking of a strong earthquake, and in several places the down-

FIG. 9. Crack along roadside south of Kealakekua, from the south, showing separation of embankment from edge of pavement due to slumping.

slope face of the fill was dislodged, allowing the material of the road bed to settle, cracking the pavement. In other places the fill appears to have settled a little merely by compaction during the jostling by the earthquake, causing cracks in the pavement.

A common occurrence was the formation of a crack parallel to the edge of the pavement on its downslope side, either within the pavement a few inches from its edge or between it and the shoulder (Fig. 9). Some of these were as much as 75 feet long and 8 inches wide. This appears to have resulted from a downslope lurching of the shoulder, moving as a separate unit from the portion of the fill beneath the pavement. The independence of movement of the shoulder and pavement was interestingly shown along the highway about 2 miles southeast of Captain Cook, where soil and sod on the shoulder were overthrust as much as an inch onto the pavement.

Damage in Cemeteries

Many headstones in cemeteries in the area near the epicenter were deranged by the earthquake. As a part of the general earthquake investigation, these cemeteries were examined, and a rough statistical study of the damage was made. Unfortunately, owing to shortage of personnel and pressure of other duties, we were delayed several days in making the cemetery examinations, and some restoration of headstones had already taken place in some cemeteries before we visited them. However, in most cemeteries little restoration had been done, and the damage remaining was probably a representative sample of the original damage. It is believed that practically all stones which had been dislodged could be detected, even after they had been replaced, by breaks or scratches on the stone or disturbance of the cement bond at the base of the stone.

There are more than 50 cemeteries in the area, but most are small family or church plots with few graves and have not been used in recent times. In some places burial was in vaults without headstones or with headstones or markers firmly cemented in place and not readily susceptible to damage by an earthquake of the intensity of the one under study. Most of the valuable information came from a few of the larger cemeteries. Damage at these is summarized in the accompanying table, and their locations are shown in Figure 1.

Derangement of headstones included overturning of stones and shifting of stones on their bases with or without rotation. In addition many grave caps were broken, some by falling or disturbance of headstones and some by lurching or slumping of the adjacent subsoil. The latter type of damage was particularly prevalent on steep slopes, where the subsoil is thick and loose. Damage of all sorts was restricted to the area between Honalo and Honokua, 5 miles northeast and 10.5 miles south-southeast, respectively, of the probable position of the epicenter.

In cemeteries north of Keauhou no damage or derangement was noted. Two miles south of Keauhou, at Lanakila cemetery in Lehuula, 4 of the 15 headstones were dislodged to the west. Inland and slightly northward, at the Daifukuji Mission in Honalo, about 5 miles

FIG. 10. Gravestone rotated counterclockwise, in Daifukuji cemetery, Kainaliu, looking approximately northwest.

north of Napoopoo, of an estimated total of 150 grave markers, 6 toppled west, 7 north, 2 east, and none south. Six had been shifted north, 16 were twisted counterclockwise, and 2 clockwise; 8 grave caps were broken (Fig. 10). It was reported that many more had been disturbed but had been restored.

At Hongwanji Mission, Kealakekua, with more than 600 graves, 12 headstones were overthrown to the west, 9 to the east, and none to the north or south. Thirty-four were twisted clockwise, 11 counterclockwise, one each shifted north, west, and south; 22 grave caps were broken.

At the Central Kona Church cemetery at Kealakekua, 12 headstones and one large memorial monument were overturned westward and one stone eastward. Another stone was rotated counterclockwise. In the Episcopal cemetery, just across the highway, five headstones were overturned westward, one was rotated counterclockwise, and one clockwise.

At Kahikolu Church, about 0.5 mile south of the Kealakekua fault line, of a total of 10 headstones, 2 were overturned to the west and one was twisted clockwise. Two miles farther inland but only about 0.6 mile south of the fault line is another cemetery of the Hongwanji Mission. Here, of more than 200 headstones, 29 were still down on September 7, the majority having been dislodged to the west, and 10 or more had been replaced. Thirteen had been twisted clockwise and 4 counterclockwise; 24 grave caps were broken. There was much damage to caps and markers in the lower section of the cemetery where the ground is composed of rocky talus.

At St. Benedict Church, 1.5 miles farther south, there is a cemetery with approximately 100 markers. Nearly half of these are wooden crosses, which were not deranged. Several others are light concrete crosses with wire reinforcing. Some of these were broken at the shank so as to expose the wires one or two of which were the sole remaining support. Of about 20 vertical headstones, 11 were displaced or broken.

The most complete derangement of gravestones was found in the Kalahiki Japanese cemetery, a small hillside cemetery 3.8 miles south of Kealia, where only 2 of 30 markers were found in position 5 days after the earthquake (Fig. 11). The dislodgement was chiefly to the southwest and, to a lesser extent, to the northeast. Ten were shifted to the north without being thrown down. Seven, including some of these 10, were rotated clockwise and one counterclockwise. Here, on loose, steeply sloping ground, a large proportion of the grave caps were broken, owing to poor design and to construction on the newly heaped grave mound. This cemetery is about 11 miles south of the probable epicenter. South of this point no cemeteries with headstones susceptible to overturning or rotation were found.

The prevailing east-west azimuth of fall of gravestones throughout the area is probably largely the result of the prevailing westward slope. The orientation of most cemeteries is governed by the general north-south alignment of the principal roads, and, in turn, most gravestones face the west or east and have

TABLE 1
SUMMARY OF DAMAGE IN CEMETERIES IN AREA EXAMINED

NAME	LOCATION	DISTANCE AND DIRECTION FROM NAPOOPOO	APPROXIMATE NUMBER OF HEADSTONES	HEADSTONES OVERTURNED						HEADSTONES ROTATED	
				NUMBER	PER CENT	APPROXIMATE DIRECTION				CLOCKWISE	COUNTER-CLOCKWISE
						N	E	S	W		
		miles									
Holualoa Japanese	Holualoa	10 N	300	0	0	0	0	0	0	0	0
Daifukuji	Honalo	5 N	150	15	10	7	2	0	6	2	16
Lanakila Church	Kainaliu	4.5 N	12	4	33	0	0	0	4	0	0
Hongwanji Mission	Kealakekua	3 N	600	21	3.5	0	9	0	12	33	10
Central Kona Church	Kealakekua	2.5 N	30	12	40	1	0	0	11	0	1
Christ Church	Kealakekua	2.5 N	60	8	13	0	3	0	5	1	1
Kahikolu Church	Napoopoo	0.5 S	10	2	20	0	1	0	1	1	0
Hongwanji Mission	Keei	1.5 SE	200	40	20	3	22	1	14	13	4
St. Benedict Church	Honaunau	3.5 SE	100	11	11	0	0	0	11	0	0
Japanese	Kalahiki	7.5 S	31	20	64	1	6	1	12	14	1

FIG. 11. Broken bases, displaced base stones, and overturned headstones in Kalahiki Japanese cemetery, south of Kealia, looking southeast. Partly because of unstable hillside ground and partly because of proximity to the epicenter, damage in this cemetery was widespread and severe; scarcely a grave escaped marked derangement.

the long dimension of their base oriented north-south. Therefore, the stones rock in an east-west direction much more easily than in any other, and, consequently, the most likely azimuth of fall is east-west. Furthermore, under sustained shaking, there is a tendency for all loose objects, including the soil cover, to work downslope to the west under the influence of gravity.

Rotation of Columns

Imamura (1937: 96) has shown that the direction of rotation of short rectangular columns, such as many headstones are, can be useful in determining the direction of motion during an earthquake and, consequently, the approximate azimuth of the line toward the epicenter. If the earthquake motion is parallel to the sides or to the diagonal (A—B, inset, Fig. 12) of the column, rotation probably will not occur. However, if the earthquake motion is in some intermediate direction, such as E—E′ in Figure 12, a rocking of the column will be accompanied by a rotational tendency. A ground motion in the direction E′ will cause the column to rock on the corner B. At the same time, the resultant of the force E′ in the direction CD will tend to rotate the column about the corner B in a counterclockwise direction. Similarly, a motion in the direction E will tend to cause a counterclockwise rotation about corner A. Directions of earthquake motion lying in the unshaded octants of the diagram tend to cause counterclockwise rotation of the column, and directions of motion in the shaded octants tend to cause clockwise rotation.

However, this law of rotation can be, and commonly is, upset by other conditions. Inhomogeneity of the terrane may cause the principal motion to be, locally, in a direction other than the azimuth pointing directly to the epicenter. Also, excentric irregularities in the bottom of the monument or its underlying base, or in the adhesion between the monument and its base, may result in rotation around those irregularities independent of the rotation described above.

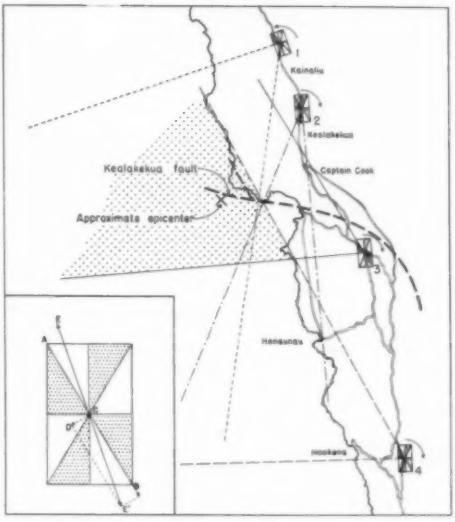

FIG. 12. Map of the central Kona area, showing the prevalent direction of rotation of monuments in cemeteries. The cemeteries are: 1, Daifukuji, Honalo; 2, Hongwanji Mission, Kealakekua; 3, Hongwanji Mission, Keei; 4, Kalahiki Japanese. At each cemetery the arrow indicates the prevalent direction of rotation. The boundaries of the octants containing the direction toward the epicenter are prolonged. The stippled area west of Captain Cook is that in which three or more of the octants overlap. The inset in the lower left is a diagram (after Imamura, 1937) of a horizontal cross section of a rectangular column, indicating the manner in which horizontal earthquake motion E—E′ causes rotation of the column.

During this study it soon became evident that, to be of value, the direction of rotation must be considered on a statistical basis. Thus, two columns only 10 feet apart in the Christ Church cemetery at Kealakekua were rotated approximately equal amounts in opposite directions. However, by using the prevailing direction of rotation of a number of columns in a single area, more useful results were obtained. The average direction of rotation of monuments in each of six cemetery areas from 5 miles north to 10 miles south of Napoopoo were all consistent with an origin of the earthquake on or near the Kealakekua fault from 2.5 to 5 miles west of Napoopoo.

Cemeteries close to the epicenter showed less consistency in the direction of rotation than did those farther away.

In Figure 12 the prevalent directions of rotation of monuments in four cemeteries are shown. Four other cemeteries were omitted because no monuments were rotated in them, or because the number of rotated monuments was too small to yield a reliable statistical result. At each of the four cemeteries plotted, the boundaries of the octants containing the direction toward the epicenter are prolonged. In an area largely west of the shoreline, from 2 miles south to 2 miles north of the approximate trace of the Kealakekua fault, three or more of the four significant octants overlap, and it is within this area of overlap that the epicenter should be situated.

LOCATION OF THE EPICENTER

Because of the dismantling of all but one of the seismographs on the island of Hawaii during the preliminary phase of the earthquake, it is not possible to locate the origin or epicenter instrumentally. The only instrumental datum available is the S—P interval of 9.5 seconds given by the Bosch-Omori seismograph at the northeast rim of Kilauea Caldera (Fig. 13). Using the travel times given by Byerly (1942: 210), this gives a distance of origin of the earthquake of approximately 47 miles from the Bosch-Omori instrument. These curves were derived for sedimentary and granitic rocks but, over a period of several years of use at the Volcano Observatory, have yielded more satisfactory and reasonable earthquake locations than any others. The use of Jones's (1935: 50) curve for duration of the preliminary waves (T*) increases the distance to only 49 miles. Taking into consideration the area of greatest intensity of the earthquake, these distances place the origin of the quake 3 to 5 miles west of the coastline in the vicinity of Napoopoo. The depth of origin appears probably to have been between 5 and 10 miles.

Some information bearing on the location of the epicenter can be derived from the study of damage by the earthquake. The general distribution of damage to roads, stone walls, and road cuts along the main highway is shown in Figure 3. This is based on a count checked against odometer mileage, assigning one unit of damage for each 1 to 15 feet of collapsed wall or road cut. Despite irregularities, the graph shows a distinctly symmetrical, bell-shaped distribution curve, with its peak about 2.5 miles by road southeast of Captain Cook. An average of more than 60 items of damage per mile in the central 5 miles decreases to only one or two per mile more than 9 miles from the center. This point of maximum damage coincides closely with the position of the buried inland extension of the Kealakekua fault. Other types of damage also were most abundant in the same general area. Together with the fact that most of the aftershocks, located by instrumental means, originated on the Kealakekua fault, it leaves little question that the origin of the major earthquake lay on or close to this fault, and that the earthquake almost certainly resulted from movement on it.

The greatest structural damage was farther south, at Hookena, where the destruction of the east and west walls of the two stone churches suggests an epicenter somewhat farther south. The possibility of a twin earthquake with one epicenter lying offshore nearly west of Hookena has been considered, but no other evidence suggests it, and no signs of a second earthquake could be detected from the seismograms either from the island of Hawaii stations or from that of the Coast and Geodetic Survey at Barbers Point on Oahu.

Throughout the Kona area, the prevalent direction of fall of rock slides, stone walls, and tombstones was westward, and the next commonest direction was eastward. The seismograms indicate that the first movement of the ground was eastward, and it is probable that some of the westward fall of objects was

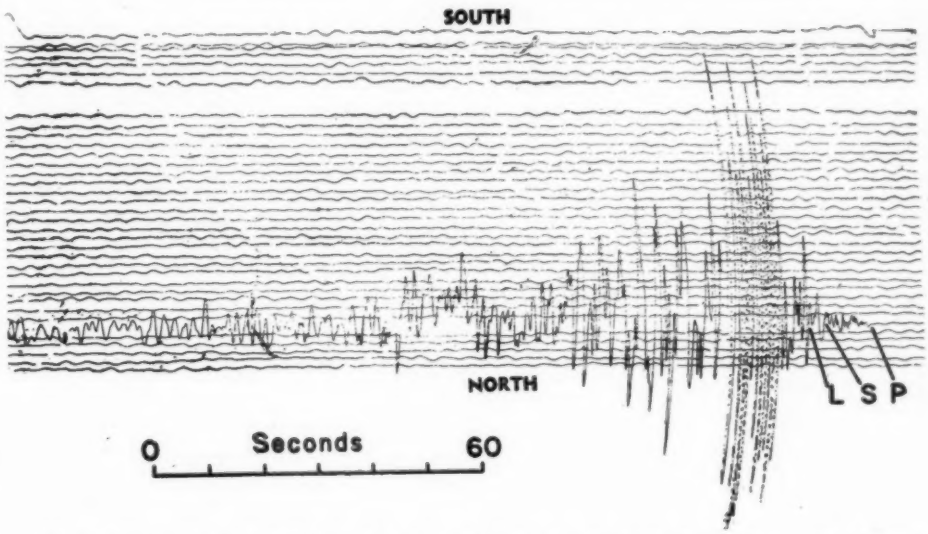

FIG. 13. Seismogram of aftershock recorded at 18:32, August 21, on the Bosch-Omori seismograph at Kilauea. Letters indicate the points of arrival of primary (P), secondary (S), and long (L) waves. The amplitude of 80 mm. on the seismogram corresponds to approximately 0.7 mm. of ground motion at Kilauea, 47 miles from the epicenter.

the result of lagging behind as the ground moved eastward under them. To some extent also, the general east-west azimuth of fall undoubtedly reflects the direction of the epicenter. However, the prevailing east-west slope appears to have been still more important in determining the direction of fall of objects. Its effects on various types of damage have already been indicated.

It has already been pointed out that the prevalent direction of rotation of columns in cemeteries indicates a location of the epicenter within the shaded offshore area in Figure 12. This area contains the seaward extension of the Kealakekua fault.

As a result of the consideration of all lines of evidence, the probable epicenter of the earthquake is placed approximately 3 miles west of Napoopoo, at latitude 19°29′ N, longitude 155°58′ W.

INTENSITY OF THE EARTHQUAKE

There are in common use two different methods of determining and expressing the strength of an earthquake. The older method is based on the observed effects of the earthquake on structures and various other objects. Based on these effects, a numerical value is assigned which is termed the intensity of the earthquake at any one point. Obviously, since the effects are less at greater distances from the origin of the quake, the intensity decreases away from the epicenter. Various scales of intensity have been proposed. That used in the present study is the modified Mercalli intensity scale of 1931 (Wood and Neumann, 1931), in which values range from 1, at which the earthquake is not felt except by a very few persons under especially favorable conditions, to 12, at which damage is total. The second method assigns a value called magnitude to the earthquake, based on the effect on standard seismographs at known distances from the origin of the quake (Richter, 1935). The magnitude is a measure of the amount of energy in the earthquake at its point of origin and, consequently, should be essentially the same at all measuring stations.

The notice of preliminary determination of

epicenter issued by the Coast and Geodetic Survey lists the magnitude of the earthquake of August 21 as 6.75 as determined at Pasadena and 7.0 as determined at Berkeley, in California.

Field studies of the effects of the earthquake indicate an intensity of 7 on the modified Mercalli scale in the area near the epicenter, decreasing to 6 at Waiohinu and Naalehu, 5 in the vicinity of Kilauea Caldera and in Hilo, and 4 at Honokaa and in the Kohala district at the north end of the island. At Honolulu, 180 miles (288 km.) from the epicenter, the intensity was 2. Populated areas of the island of Hawaii are largely restricted to the periphery of the island. The interior portions of the island are almost wholly unpopulated, making it impossible to draw accurate isoseismal lines. Approximate isoseismals are shown in Figure 1.

Given a single impulse, the minimum horizontal acceleration that can cause the sliding of a short stone column on a stone base is 71 per cent of the value of gravity, decreasing to 57 per cent at an angle of emergence of 35° to the horizontal (Imamura, 1937: 105). Because the sliding of headstones and, especially, base plates was common in cemeteries during the August 21 earthquake, it might be concluded that the acceleration during the earthquake was at least six tenths that of gravity. However, Imamura (1937: 106) also has shown that small, short-period vibrations in the epicentral areas of strong earthquakes, although they do not themselves cause the displacement of objects, may so lower the normal values of the coefficients of friction that sliding can be caused by longer period vibrations with accelerations much less than six tenths that of gravity. The presence of such vibrations in the Kona area is suggested by local vagaries of displacement and by other behavior. The acceleration which caused the lateral displacement of objects during the Kona earthquake is not known but probably was much less than six tenths that of gravity.

CONCLUSION

The earthquake of August 21, 1951, like most of its aftershocks, probably was caused by movement on the Kealakekua fault. This is one of a number of similar faults along which the lower slopes of Mauna Loa and Kilauea Volcanoes have moved relatively downward and outward toward the deep ocean. In this sense the earthquake was tectonic in origin.

In one sense, of course, all earthquakes in Hawaii are volcanic in origin. However, the August 21 earthquake cannot be directly related to any specific volcanic episode. It is possible that it is related in some way to the great extravasation of lava during the 1950 eruption of Mauna Loa, but there is no evidence to demonstrate such a relationship. On September 16 a series of smaller earthquakes originated on the Kaoiki fault system, a series of fractures corresponding to the Kealakekua fault, on the southeast slope of Mauna Loa. From mid-May until early July abnormally rapid eastward tilting at Kilauea Caldera indicated a tumescence of Mauna Loa Volcano. There is a possibility that both the August 21 earthquake and its aftershocks and the September 16 earthquakes were caused by a slight upward movement of the central portion of Mauna Loa in relation to the lower slopes. The August 21 earthquake has no known connection with any coming volcanic activity, though such a relationship may yet appear.

The southern part of the island of Hawaii is subject to frequent earthquakes, but few are as intense as that of August 21, 1951. The great earthquake of April 2, 1868, judging from the descriptions of damage, was much more severe. Wood (1914) assigned to it an intensity of 10. Its epicenter was farther south, near Waiohinu in Kau, where extensive surface faulting took place. The earthquakes of March 28 and April 3, 1868, also were probably at least as severe as that of August, 1951. The earthquake of October 6, 1929, centered beneath Hualalai Volcano, had a magnitude

of 6.5 (Gutenberg and Richter, 1949: 207), and caused damage as far south as Captain Cook. The Maui earthquake on January 23, 1938, had a magnitude of 6.75, about the same as that assigned by the California Institute of Technology Seismological Laboratory in Pasadena for the earthquake of August 21, 1951. During the years from 1929 to 1945, Gutenberg and Richter (1949, table 17) list eight earthquakes of magnitude 5 and over which originated in the general Hawaiian area. During the same interval they list 58 earthquakes in California with magnitude of 5 or more and 127 in Japan and Kamchatka. Thus, during those years, California had about seven times as many large earthquakes as the Hawaiian area, and the Japan-Kamchatka area had about 16 times as many. However, there are some areas, such as the northeastern United States, which have far fewer earthquakes than the Hawaiian area.

Based solely on the 1929–1945 interval, the Hawaiian area can expect an average of about one earthquake of magnitude 5 or more every 2 years. However, during the past century, there have been only six earthquakes of intensity comparable to that of August 21, and no other appears to have been quite as severe in central Kona. There is, of course, no assurance that another equally or even more severe earthquake might not occur in that area in much less time than a century. It might occur within the next few months, but, judging from the past, that is quite unlikely.

Well-built structures, with footings of better quality than many of those now found in Kona, will minimize or even eliminate the damage resulting from the lesser earthquakes which the Kona area experiences frequently in common with all the island of Hawaii except the northernmost part. However, it may not be economically feasible to build in such a way as to eliminate damage from the infrequent large earthquakes.

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The Genus *Acer* (Maples) in Formosa and the Liukiu [Ryukyu] Islands

HUI-LIN LI[1]

THE SPECIES of the genus *Acer* in Formosa and the Liukiu Islands are included in the revisional study of the family Aceraceae made by Fang (1939). The Formosan species are also treated by Kanehira in his work on the Formosan trees (1936). The opinions expressed by these two authors are widely divergent. Fang accepts practically all the species originally described from Formosa, whereas Kanehira reduces a large number to synonymy. Neither of the two treatments is exhaustive, as a few names pertaining to Formosan plants are omitted from each.

For purposes of the present study, the works of these two authors, as well as other pertinent literature, have been critically reviewed. Specimens deposited in the U. S. National Herbarium, Smithsonian Institution, and the herbarium of the National Taiwan University, Formosa, have been studied and are cited, with the abbreviations US and NTU, respectively. In the latter case, only selected specimens are listed. As a result of this study, eight species are recognized for Formosa and one for the Liukiu Islands. The Liukiu entity was formerly considered a variety of a Chinese species, but it is here raised to specific rank. Two new varieties are proposed herein, and several new synonyms are noted.

KEY TO THE SPECIES IN FORMOSA AND LIUKIU ISLANDS

A. Leaves entire.
  B. Leaves undivided, rarely indistinctly 3-lobed.
    C. Leaves glaucous beneath.
      D. Leaves obtuse or cuneate at base, not 3-nerved. 1. *A. albopurpurascens*
      DD. Leaves rounded to cordate and distinctly 3-nerved at base. . . . . 2. *A. itoanum*
    CC. Leaves white-pubescent beneath. . . . . 3. *A. hypoleucum*
  BB. Leaves 3-lobed. . . . . 4. *A. buergerianum* var. *formosanum*
AA. Leaves serrate.
  B. Leaves undivided to shallowly 3- or rarely 5-lobed.
    C. Leaves mostly undivided, sometimes shallowly 3- or rarely 5-lobed; inflorescence racemose.
      D. Fruit 2–2.2 cm. long. . . . . 5. *A. kawakamii*
      DD. Fruit 2.5–3 cm. long. . . . . 5a. *A. kawakamii* var. *taitonmontanum*
    CC. Leaves distinctly 3–5-lobed; inflorescence cymose. . . . . 6. *A. tutcheri* var. *shimadai*
  BB. Leaves distinctly 5- or 7-lobed.
    C. Leaves all 5-lobed.
      D. Leaves shallowly 5-lobed; fruit 1.8–2.3 cm. long. . . . . 7. *A. rubescens*
      DD. Leaves deeply 5-lobed; fruit 2.5 cm. long. . . . . 8. *A. serrulatum*
    CC. Leaves all 7-lobed. . . . . 9. *A. palmatum* var. *pubescens*

1. **Acer albopurpurascens** Hay. (1911: 64).

Acer litseaefolium Hay. (1913: 66, pl. 14, b). *Acer oblongum* sensu Matsum. & Hay. (1906: 96); Koidz. (1911*b*: 55), p. p.;

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Kanehira (1936: 506, fig. 361) [non Wall.].

Acer lanceolatum sensu Rehder (1905: 180) p. p. [non Molliard].

An evergreen tree to 15 cm. high; branchlets pubescent at first, soon glabrous. Leaves persistent, coriaceous, oblong-lanceolate, 6–13 cm. long, 2.5–5 cm. broad, caudate to acuminate at apex, obtuse to cuneate at base, pale green and glabrous above, white-purplish-glaucous beneath, densely pubescent when young, weakly 3-nerved at base, the basal nerves short, slightly raised or indistinct, the lateral nerves 7–10 per side, slightly raised, divergent at right angles; petioles 1.5–3 cm. long, glaucous. Infructescence cymose; nutlets glabrous, about 3 mm. across; wings with nutlets about 2 mm. long, spreading at obtuse angles.

Endemic to Formosa; in forests from medium to low altitudes throughout the island.

Formosa: South Cape, *A. Henry 1257* (US); Musha, Nanto Prov., *E. H. Wilson 10082* (US); Kizan-gun, Takao-syu, *Y. Yamamoto & K. Mori 808* (NTU).

The concept of *A. oblongum* Wall. in eastern Asia has been considerably modified in recent years. The species is now considered as occurring only in northeastern India and western China, and other plants of this immediate relationship from eastern and southern China are considered to represent distinct species by recent authors, perhaps too many such species being recognized. Hayata earlier established three species of this group in Formosa, namely *A. albopurpurascens*, *A. litseaefolium*, and *A. hypoleucum*, but later workers on the Formosan flora, including Kanehira (1936) and Sasaki (1930: 325), consider them as a single species, to which they refer as *A. oblongum* Wall. Metcalf (1932: 198) and Fang (1939: 145–163) maintain all three as distinct. The Formosan plant, under the current concept, should be specifically distinguished from *A. oblongum* especially because of the weak or indistinct basal nerves. But probably only one species is present on the island; the identity of *A. hypoleucum* is somewhat uncertain.

A plant from the Liukiu Islands, considered as a variety of *A. oblongum*, has distinct morphological characters and an outlying range. It should be treated as a separate species.

2. ***Acer itoanum*** (Hay.) comb. nov.

Acer oblongum Wall. var. *itoanum* Hay. (1911: 67); Metcalf (1932: 196); Fang (1939: 138).

Acer oblongum var. *microcarpum* sensu Ito ex Ito & Matsum. (1898: 387) [non Hieronymus].

Acer oblongum sensu Koidz. (1911*b*: 55, pl. 29) p. p.

Tree to 13 m.; branchlets glabrous, the young ones reddish, the older grayish. Leaves thin-coriaceous, glabrous, ovate to broadly ovate, 4.5–6.5 cm. long, 2–4.5 cm. broad, abruptly acuminate at apex, rounded to cordate at base, entire at margins, usually undivided, rarely indistinctly and obtusely 3-lobed, green above, glaucous beneath, distinctly 3-nerved at base, the veins distinct on both surfaces, the basal nerves long and strongly ascending, the lateral nerves 3–5 per side, the veinlets densely reticulate, elevated and distinct on both surfaces; petioles slender, to 2.5 cm. long, glabrous. Flowers unknown. Infructescence terminal, corymbose, pubescent; peduncles about 1 cm. long; pedicels to 1 cm. long, slender, pubescent. Fruit brownish yellow; nutlets convex, 5–6 mm. long, 3–4 mm. broad; wings oblong, with nutlets about 1.5–2 cm. long, 5 mm. broad, spreading at about 45–90°.

Endemic to the Liukiu Islands.

Liukiu Islands: Okinawa, *W. D. Field & O. G. Loew 4* (US); Shuri, *E. H. Wilson 8172* (US), *C. Wright 40* (US).

This species differs from *A. oblongum* Wall. in the small, short, ovate leaves, which are abruptly acuminate at apex and distinctly

rounded to cordate at base, as well as in the smaller fruits with pubescent pedicels. The wings of the fruit are oblong rather than ovate in shape. Among the specimens cited, *Field & Loew 4* has the leaves mostly broader and more distinctly cordate, with a few having a tendency toward being indistinctly 3-lobed. The illustration given by Koidzumi, showing leaves with round to cordate bases, evidently refers to the Liukiu plant.

3. **Acer hypoleucum** Hay. (1913: 66, pl. 14, c).

Small tree; branchlets slender, tomentose at first, soon glaucous. Leaves persistent, chartaceous to coriaceous, oblong or elliptic-oblong, about 8 cm. long, 3.5–4 cm. broad, obtuse or acutish at apex, rounded or obtuse at base, entire or slightly undulate at margins, green above, whitish-glaucescent and densely tomentose beneath, slightly 3-nerved at base, the nerves raised and more or less distinct, the lateral nerves 5 or 6 per side; petioles 2–3 cm. long, slender, tomentose. Infructescence cymose, terminal; nutlets convex, about 5 mm. across; wings with nutlets about 17 mm. long and 6 mm. broad, spreading at nearly right angles; pedicels 1.5 cm. long, slender, pubescent.

Endemic to Formosa; no specimen seen.

Acer hypoleucum is described as being pubescent on the lower surface of the leaves. It is thus maintained as distinct from *A. albopurpurascens* by Metcalf and Fang; the latter has seen the type. However, Kanehira relegates it, together with *A. albopurpurascens*, to the synonymy of *A. oblongum* (sensu Kanehira non Wall.). In *A. albopurpurascens*, the young leaves are densely pubescent, as shown in *Wilson 10082*. The presence or absence of these hairs may be due to variation in age and environment. Further studies are needed to ascertain the identity of *A. hypoleucum*.

4. **Acer buergerianum** Miquel var. **formosanum** (Hay.) Sasaki (1928: 275); Fang (1939: 128).

Acer trifidum Hook. & Arn. var. *formosanum* Hay. ex Léveillé (1906: 593); Koidz. (1911*b*: 30, pl. 17, 8–9); Kanehira (1936: 409, fig. 364).

Tree to 10 m. high; branchlets glabrescent. Leaves deciduous, membranaceous, ovate to elliptic, 8–10 cm. long, 4–6 cm. broad, rounded or slightly cordate at base, entire or shallowly 3-lobed near apex, 3-nerved at base, the reticulations conspicuous; petioles 2.5–5 cm. long. Inflorescence corymbose. Fruits yellowish brown; nutlets strongly convex, about 6 mm. across; wings falcate, with nutlets 2.5–3 cm. long, 8–10 mm. broad, spreading horizontally.

Formosa: Huki-kaku, *T. Kawakami*, May 1915 (NTU).

The species occurs in southeastern China, the variety is endemic to the coast of northern Formosa, in forests. Fang maintains the variety on the basis of the type specimen, which he examined.

5. **Acer kawakamii** Koidz. (1911*a*: [102] [March]; 1911*b*: 15, pl. 5 [Aug.]); Kanehira (1936: 402, fig. 360).

Acer caudatifolium Hay. (1911: 65 [June]).
Acer morrisonense Hay. (1911: 66, ex Koidz. 1911*a*: 16, pl. 7).
Acer ovatifolium Koidz. (1911*a*: [102]); (1911*b*: 16, pl. 6).
Acer caudatum sensu Matsum. & Hay. (1906: 96) [non Wall.].

A tree to 20 m. high; branchlets slender, glabrous. Leaves deciduous, chartaceous, ovate to ovate-oblong, 6–10 cm. long, 3–5 cm. broad, caudate-acuminate at apex, rounded or slightly cordate at base, serrate and sometimes shallowly 3- or rarely 5-lobed at margins, 5-nerved at base, the lateral nerves 7 or 8 per side, green above, pale green beneath, slightly pubescent on nerves at first, soon glabrous; petioles 3–4 cm. long, rosy, slender, glabrous. Flowers in glabrous or slightly pubescent racemes about 5 cm. long; sepals 5, emarginate, 2–2.5 mm. long; petals 5,

white, emarginate, 3.5–4 mm. long; stamens 8, shorter than the sepals; ovary glabrous; pedicels 5–6 mm. long, slender, glabrous. Fruit yellowish brown; nutlets about 5 mm. across; wings falcate, with nutlets 2–2.2 cm. long, 8–12 mm. broad, spreading at obtuse angles; pedicels 6–7 mm. long.

Endemic to Formosa, in forests of high mountains in the central range, from 2,000 to 2,500 meters.

Formosa: Mt. Taipinshan, *H. Keng 1224* (NTU, US); Arisan, *E. H. Wilson 9643* (US), *10830* (US).

Fang (*loc. cit.*) maintains *A. morrisonense* and *A. taiton-montanum* as distinct species, but Kanehira reduces both to the synonymy of *A. kawakamii*. *A. taiton-montanum* is here treated as representing a variety of the latter species. *A. ovatifolium* Koidz. is suggested by Fang (1939: 181) as "probably identical with *Acer kawakamii* Koidzumi," and I think this is where it should be referred. As undivided and lobed leaves are often found on the same plant, this character alone is apparently not constant enough for specific distinction.

5a. ***Acer kawakamii*** Koidz. var. ***taitonmontanum*** (Hay.) comb. nov.

Acer taiton-montanum Hay. (1913: 67).

Leaves chartaceous, triangular-ovate, 5–7 cm. long, 4–5 cm. broad, the margins doubly serrate, undivided or shallowly 3- or 5-lobed. Fruiting racemes to 4 cm. long; nutlets slightly concave, about 1 cm. long and 5 mm. broad; wings with nutlets 2.5–3 cm. long, about 8 mm. broad, spreading at right angles; pedicels 6–7 cm. long, glabrous.

Endemic to Taiton Mountains, northern Formosa, near sulfur hot springs at about 650 meters altitude.

Formosa: Sozan, Taihoku-syu, *T. Tanaka & Y. Shimada 11006* (US), *E. H. Wilson 11229* (US), *N. Fukuyama 8010* (NTU).

Acer taiton-montanum is treated as a synonym of *A. kawakamii* by Kanehira and as a distinct species by Fang. It is very close to *A. kawakamii*, differing only in the larger fruit. The leaves also vary from undivided to 3- or rarely 5-lobed. The typical variety of *A. kawakamii* occurs in the high central mountains from 2,000 to 3,000 meters, whereas this variety is confined to the Taiton Mountains in northern Formosa at an altitude of about 650 meters, near sulfur hot springs. This is an interesting case of ecological differentiation. There are similar examples in other plants occurring in these two localities.

6. **Acer tutcheri** Duthie var. **shamadai** Hay. (1911: 70); Kanehira (1936: 405).

Acer oliverianum subvar. *trilobatum* Koidz. (1911*b*: 34, fig. 2).

A deciduous tree. Leaves broadly rhomboid, about 15 cm. long and 7 cm. broad, 3-lobed, rounded at base, distinctly 3-nerved, serrulate at margins, subentire toward base, the lobes similar in size or the basal ones slightly smaller, the terminal lobe broadly triangular, about 2.5 cm. long and 3 cm. broad; petioles about 4 cm. long. Infructescence cymose, terminal, about 6 cm. broad and 7 cm. long including the peduncles of 2–3 cm.; fruit glabrous, the nutlets ovoid, about 4.5 mm. long; wings with nutlets about 1.5 cm. long and 6 mm. broad, divaricate at about 40°.

Endemic to Formosa, central mountains, in forests. No specimen seen.

The typical variety of *A. tutcheri* is confined to Kwangtung and Kwangsi. The Formosan plant, as described by Hayata, appears to be very close to it except in the smaller fruit and much less divaricate wings. This variety is not treated in Fang's revision.

7. **Acer rubescens** Hay. (1911: 66); Koidz. (1911*b*: 21, pl. 11); Kanehira (1936: 405, fig. 363).

A deciduous tree, 10–20 m. high; branchlets glabrous. Leaves chartaceous, roundish-ovate in outline, 6–10 cm. long, 5–8 cm. broad, truncate or subcordate and 5-nerved

at base (lateral nerves 5 or 6 per side), doubly serrate at margins, green above, glabrous beneath, shallowly 5-lobed, the middle lobe shortly ovate, acuminate or caudate-acuminate at apex, the lateral lobes smaller, acute to obtusish at apex; petioles 5–7 cm. long. Fruits yellowish brown, small, racemose; nutlets subellipsoidal, about 6 mm. long and 4 mm. broad; wings with nutlets 1.8–2.3 cm. long, 6–7 mm. broad, divaricate at 90–110°; pedicels 7–10 mm. long, slender, glabrous.

Endemic to Formosa, in forests at high altitudes of 1,800–2,200 meters, central ranges.

Formosa: Mt. Taihei, Taihoku-syu, *S. Suzuki 247* (NTU); New Paisienshan, *H. Keng*, Nov. 5, 1950 (NTU, US).

8. **Acer serrulatum** Hay. (1911: 70).

Acer oliverianum Pax var. *nakaharai* Hay. (1911: 68); Koidz. (1911*b*: 33, pl. 20); Kanehira (1936: 405, fig. 362).
Acer oliverianum Pax var. *nakaharai* Hay. f. *longistaminum* Hay. (1911: 69).
Acer oliverianum Pax var. *microcarpum* Hay. (1911: 69).
Acer oliverianum Pax var. *nakaharai* subvar. *formosanum* Koidz. (1911*b*: 33, fig. 1).

A tree up to 20 m. high; branchlets reddish, glabrous. Leaves rounded-cordate to broadly orbicular, about 7–7.5 cm. long and 9–10 cm. broad, glabrous on both surfaces, cordate at base, the nerves about 5 per side, the veinlets finely reticulate, distinct on both surfaces, palmately 5-lobed, the lobes more or less equal or the lower smaller, triangular-lanceolate to triangular-ovate, irregularly or duplicately crenate-serrate, the terminal lobe about 5–7.5 cm. long and 1.5–2 cm. broad; petioles 2–2.5 cm. long, glabrous. Flowers in terminal cymose inflorescences; peduncles 3–5 cm. long, glabrous; pedicels to 6 mm. long; sepals 5, rounded-oblong, 2 mm. long, hirsute toward the apex on both surfaces, the margins tomentose-ciliate; petals 5, yellow, rounded, 1.25 mm. long, obscurely denticulate to subentire at margins; stamens 5–7, the filaments 1 mm. long, the anthers oblong, 1 mm. long; ovary 0.6 mm. long, hirsute; styles 2, connate, about 2 mm. long; disc thick, 5–7-lobed, the lobes rounded. Nutlets ellipsoid-oblong, about 14 mm. long; wings obovate, with nutlets 2.5 cm. long, divaricate at 90–120°.

Endemic to Formosa, common in forests at altitudes of 1,000–2,000 meters throughout the island.

Formosa: Sozan, *E. H. Wilson 10786* (US); Taihoku, *E. H. Wilson 10129* (US); Mt. Morrison, *H. H. Bartlett 6297* (US); Bunzan-gun, Taihoku-syu, *T. Suzuki 18390* (NTU); between Pianan and Sikayo, *G. Masamune 1082* (NTU), Kiriyama and Tiponzae, *S. Suzuki 11019* (NTU).

This species is the largest tree of the genus on the island, widely distributed and very common in forests at altitudes of about 1,000–2,000 meters. Although some variations in the leaves are found, the plants from different localities clearly represent a single species. Kanehira's combination of *A. serrulatum* and *A. oliverianum* var. *nakaharai* is thus followed. The type of *A. serrulatum* is a sterile specimen, and for this reason, Fang (1939: 87), who has examined the type, could not ascertain the identity of the species. Earlier, however, Koidzumi, who also had access to the type, had already listed Hayata's name in the synonymy of *A. oliverianum* var. *nakaharai* Hay.

This species is here considered as distinct from *A. oliverianum* of western China. It differs from the latter in the more deeply serrate leaves, with crenate instead of sharply appressed serrations. The sepals are densely hirsute and the stamens are shorter than in *A. oliverianum*. Furthermore, *A. serrulatum* has the fruit-wings divaricate at about 120°, whereas in *A. oliverianum* the fruit-wings are spreading horizontally.

In *A. oliverianum*, Koidzumi described another subvariety, *A. oliverianum* var. *nakaharai* subvar. *trilobum* Koidz., with 3-lobed leaves. This, as noted above, is now known as *A.*

tutcheri Duthie var. *shimadai* Hay. Another variety with 3-lobed leaves, described from the neighboring province Fukien, should be considered as a distinct species: *A. johnedwardianum* Metcalf (1942: 221). (*A. wilsonii* Rehder var. *serrulatum* Dunn in Linn. Soc. London, Jour., Bot. 38: 358, 1908; *A. oliverianum* Pax var. *serrulatum* (Dunn) Rehder in Sarg., Pl. Wils. 1: 90, 1911; non *A. serrulatum* Hay.). *A. oliverianum* occurs from eastern to southwestern China, while *A. johnedwardianum* is localized in Fukien. It differs from the former in the 3-lobed leaves, which are glabrous and rounded at base, and in the smaller fruits, which are arranged in a slender corymb.

9. ***Acer palmatum*** Thunb. var. ***pubescens*** var. nov.

Acer duplicato-serrulatum Hay. (1911: 70).
Acer palmatum Thunb. subsp. *matsumurae* Koidz. var. *spontaneum* Koidz. subvar. *formosanum* Koidz. (1911*b*: 50).
Acer ornatum Carr. var. *matsumurae* Koidz. α. *spontaneum* (Koidz.) Nemoto subvar. *formosanum* (Koidz.) Nemoto (1936: 454).
Acer matsumurae Koidz. var. *formosanum* Sasaki (1930: 324) [nomen nudum].

A typo speciei differt ramulis novellis, foliis utrinque, petiolis, inflorescentiisque molliter pubescentibus.

A small tree, young branchlets slender, white-villose-pubescent, becoming glabrescent and glabrous. Leaves to 5 cm. long, subcordate, deeply 5-lobed, the base cordate, the lobes lance-oblong, acuminate, subduplicately serrate, villose especially on the veins on both surfaces, the lobes parted to beyond the middle; petioles glabrous, slender, 2.5 cm. long, villose-pubescent. Inflorescence in small corymbs, densely villose-pubescent at first; peduncles 1–2.5 cm. long; pedicels 5–6 mm. long; sepals slightly purplish, ovate-oblong, 2–3 mm. long, more or less glabrous; petals slightly smaller than the sepals, white; stamens short, included, the filaments about 1 mm. long, the anthers about equal in length; ovary densely villose.

Endemic to mountain forests at altitudes of about 1,600 meters, central and northern parts.

Formosa: Taranan, Bunzan-gun, Taihoku-syu, *T. Suzuki 17859* (NTU, type); Mt. Taihei, *S. Sasaki*, Sept. 2, 1925 (NTU).

The nomenclature of cultivated and wild forms of *A. palmatum* Thunb., as adopted by several Japanese botanists, is very varied and confusing. The wild plant growing spontaneously in the mountains of Formosa differs from the Japanese plants chiefly in the pubescence being present not only on the young branches and inflorescences, but also on mature leaves and petioles. As it is geographically isolated from other plants of this species, it is here considered as a distinct variety.

Acer duplicato-serrulatum Hay. is listed as a synonym of *A. oliverianum* var. *nakaharai* = *A. serrulatum* by Kanehira. This is evidently incorrect, as the former has 7-lobed leaves, while the latter has 5-lobed leaves. This name is not taken up by Fang. However, Koidzumi, who had access to Hayata's type, earlier identified this with the wild form of *A. palmatum* from Formosa. The type, as noted by Koidzumi, is a sterile specimen.

Acer matsumurae Koidz. var. *formosanum* Sasaki was published without description or reference, hence is a nomen nudum and invalid.

EXCLUDED SPECIES

Acer taiwanense Yamamoto, Soc. Trop. Agr., Jour. [Formosa] 5: 180, fig. 6, 1933.

This name, not listed by Kanehira but by S. Suzuki (1936: 129), is, as noted by Fang (1939: 246), actually based upon a specimen collected in Cochin-China. It should be eliminated from the list of plants of Formosa.

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A New Species of Amphipod from Lower California (Genus *Eriopisa*)[1]

J. Laurens Barnard[2]

Among recent collections of amphipods made by Dr. John S. Garth along the coast of Lower California, from the research vessel "Velero IV," were those reported upon here, a new species belonging to the genus *Eriopisa* Stebbing (1890: 193). I am pleased to name this amphipod for Dr. Garth, in whose laboratory the work was carried out, and whose counsel for several years has been greatly appreciated. I am also indebted to Captain Allan Hancock, Director, and Dr. James W. Buchanan, Director of Research, Allan Hancock Foundation, for support and equipment.

Eriopisa garthi new species

Figs. 1, 2

Description of male.—Head nearly as long as first 2 body segments, lateral lobes strongly produced, obtuse. Eyes not visible.

Antenna 1 about as long as head and peraeon combined, articles 1 and 2 of peduncle subequal in length, article 3 about half as long as article 2. Flagellum slender, 1.5 times as long as peduncle, with as many as 16 articles. Accessory flagellum with 2 articles, longer than first article of primary flagellum.

Antenna 2 reaching slightly beyond end of peduncle of antenna 1, articles 4 and 5 equal in length, flagellum slightly longer than article 5 of peduncle.

Mandible: Molar conical, primary plate with 4–5 teeth, accessory plate with 4 teeth, spine row with 5 simple spines. Palp article 3 two thirds as long as article 2.

Lower lip: Inner and outer lobes well developed, apices rounded, mandibular lobes short.

Maxilla 1: Inner plate with 3 long setae and 2 small, medial setae, outer plate with 9 spines; apex of palp article 2 with an acute tooth, 3 spines and 2 setae.

Maxilla 2: Inner plate broader than outer, inner edge lined with several strong setae.

Maxilliped: Inner plate subrectangular, apex truncate, but with rough indentations, armed with 3 spines and several setae; outer plate reaching to middle of palp article 2, strongly armed with setae. Palp article 4 slender, conical, curved, about as long as article 3.

Gnathopod 1: Coxa not triangular, infero-anterior edge rounded; article 2 rather stout; article 4 large, posterior surface echinulate; article 5 slightly longer than 4, attached along the anterior surface of the latter; article 6 longer than 5, palm oblique, convex, lined with setules, defined by a spine; article 7 slender, curved, longer than palm.

Gnathopod 2: Articles 4 and 5 short; article 5 produced into a posterior setose lobe; article 6 very large, elongate, palm with a large, subacute medial tooth bearing spinules, posterior to which the palm is hemispherically excavated; the posterior wing of the excavation bearing 3 spines; article 7 strong, curved, fitting palm.

Peraeopod 1 slightly larger than 2, slender, articles 4 and 5 equal in length, shorter than article 6; article 7 slightly curved.

Peraeopod 3 shorter than 1, coxa produced

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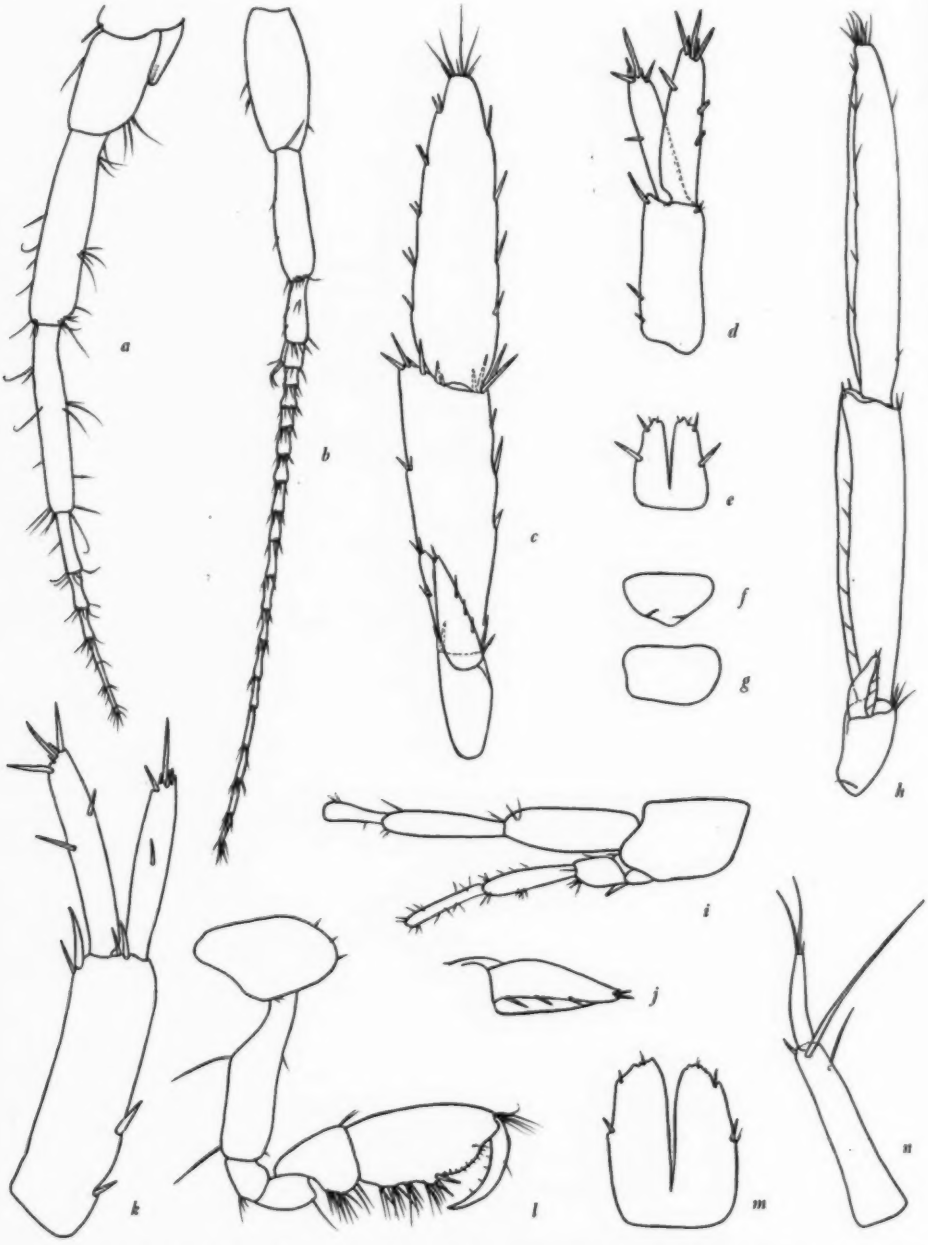

FIG. 1. *Eriopisa garthi* n. sp.: *a*, Antenna 2; *b*, antenna 1; *d*, uropod 2; *f*, coxa 6; *g*, coxa 4; *h*, uropod 3; *i*, head; *j*, uropod 3, inner ramus; *k*, uropod 1; *m*, telson; *n*, accessory flagellum (male, paratype, 8.5 mm.); *c*, uropod 3; *e*, telson; *l*, gnathopod 1 (female, allotype, 8 mm.).

downward anteriorly into a rounded lobe, article 2 not broadly expanded, posterodistal corner produced downward into a rounded lobe; articles 5 and 6 equal in length, longer than 4.

Peraeopods 4 and 5 successively longer, peraeopod 4 intermediate in size between 3 and 5, peraeopod 5 greatly elongated; coxae triangular in shape, not lobed; posterodistal corner of article 2 produced downward into a subacute lobe, articles 4–6 successively longer; article 4 about as long as 2.

Pleopods: outer ramus shorter than inner, both elongated, longer than peduncle, each with 9 articles.

Uropods 1 and 2 short, not reaching much beyond last urosome segment. Uropod 1 reaching to end of uropod 2, inner ramus nearly as long as peduncle, outer ramus shorter than inner.

Uropod 2: Inner ramus subequal in length to peduncle, longer than outer ramus.

Uropod 3 greatly elongated, nearly one half the length of the body. Peduncle very short; inner ramus shorter than peduncle, conical, tipped with 2 spinules; outer ramus very long, more than 5 times as long as peduncle, composed of 2 flattened articles slightly curved upward at the edges, the distal article slightly longer than the proximal one, rounded distally and apically setose.

Telson split, lobes broad, apices oblique, serrate, each lobe armed with 2 spines and a setule.

Body very slender, none of the segments dorsally carinate or toothed.

Pleon segment 3: Lower posterior corner produced into an acute tooth.

FEMALE.—Differing from the male by the small second gnathopods, article 6 of which resembles gnathopod 1; and by the shorter and broader third uropods on which the inner ramus is about one half the length of the proximal article of the outer ramus. Apices of telson more acute (possibly due to the juvenility of the females available, as young males show this same characteristic).

TYPES.—Holotype, Allan Hancock Foundation No. 513, male, 7.2 mm.; paratype, 8.5 mm. (figured); allotype, female, 5 mm. (figured).

TYPE LOCALITY.—"Velero" Station 2066–51, Punta Eugenia, Lower California, Mexico, November 1, 1951, intertidal, under rock on gravel.

MATERIAL EXAMINED.—The types and 12 other specimens from the type locality.

REMARKS.—Four species belonging to the genus *Eriopisa* were previously known. These are *Eriopisa elongata* (Bruzelius, 1859), *E. philippensis* (Chilton, 1920), *E. chilkensis* (Chilton, 1921), and *E. seurati* Gauthier (1936). They are characterized generally by the following characters: (1) Inner edge of inner plate on maxilla 1 strongly setose; (2) setae present on inner edge of inner plate of maxilla 2; (3) lower anterior edge of coxa 1 not greatly prolonged; (4) mandibular palp with setae well developed on article 3 and several on article 2, palp well developed structurally; (5) gnathopod 2 much larger than 1. The new species treated here agrees in concept with items 2–5 but not with item 1, as the present material has only 3 well-developed setae on the inner edge of the inner plate of maxilla 1, a characteristic of the closely related genus *Eriopisella* Chevreux (1920). The latter was separated from *Eriopisa* by the paucity of setae on the inner plates of the first two maxillae.

The known species of the genus *Eriopisella* are *E. pusilla* Chevreux (1920), *E. capensis* (K. H. Barnard, 1916), and *E. sechellensis* (Chevreux, 1901). The present species is separated from these by the presence of setae on the inner edge of the inner plate of maxilla 2, by the rounded first coxal plate, by the armature and stoutness of the mandibular palp, by the large size of the distal article of the outer ramus of uropod 3, and by the diversity in size of the first 2 pairs of gnathopods.

Although transgressing the defining characters of the genera *Eriopisa* and *Eriopisella*

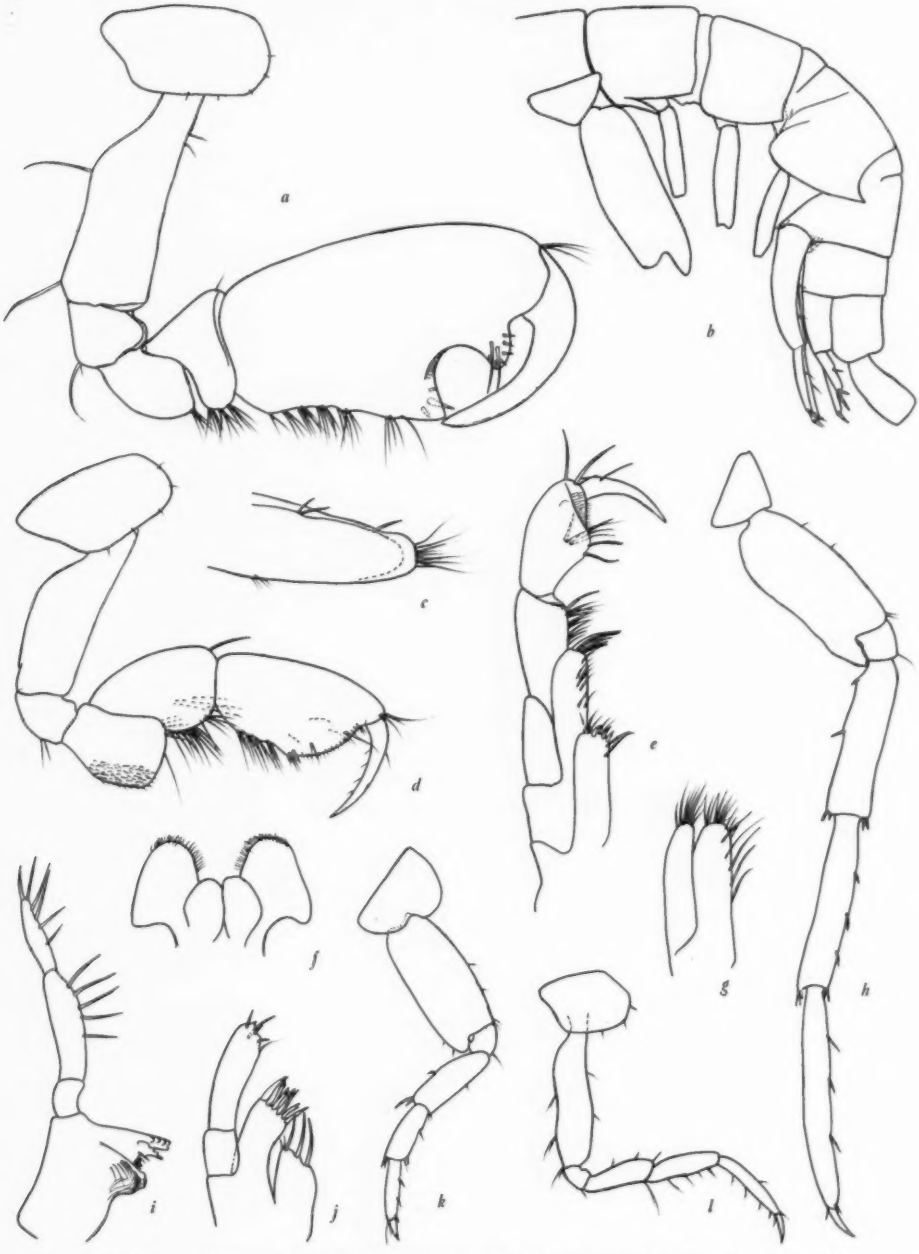

FIG. 2. *Eriopisa garthi* n. sp.: *a*, Gnathopod 2; *b*, pleon, left side; *c*, uropod 3, apex; *d*, gnathopod 1; *e*, maxilliped; *f*, lower lip; *g*, maxilla 2; *h*, peraeopod 5; *i*, mandible; *j*, maxilla 1; *k*, peraeopod 3; *l*, peraeopod 1 (male, paratype, 8 mm.).

as stated by Chevreux (1920), with regard to the lack of setae on maxilla 1, the new species fits into the genus *Eriopisa* on the basis of characters 2–5 as stated above. It differs from the known species in the genus not only by the character of maxilla 1, inner plate, but also by the character of article 6 of gnathopod 2, wherein the palm is deeply excavated.

This is the first record of the genus *Eriopisa* on the Pacific Coast of North America.

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The Nassariidae of the West Coast of North America between Cape San Lucas, Lower California, and Cape Flattery, Washington

JOAN DEMOND[1]

THE MOLLUSCS which constitute the family Nassariidae are worldwide in distribution and include several hundred species. The family has long been, and still is, in need of complete taxonomic revision. However, such a revision is beyond the scope of this paper, which is arbitrarily limited to a consideration of those species of Nassariidae found living on the west coast of North America within the area between Cape San Lucas, Lower California, and Cape Flattery, Washington.

A summary of the known ecology of these molluscs was thought valuable since the literature on this subject is scattered and difficult of access. To the author's knowledge, no such compilation has previously been attempted.

As far as possible, detailed synonymies, shell descriptions, distributional records, and habitat remarks have been compiled for each of the 12 species and two subspecies found in this area. Revisions of the west coast faunal list are suggested. A key based entirely upon external shell characteristics of adult specimens is presented. Illustrations of all west coast species are included.

In making this study, collections were examined at the California Academy of Sciences in San Francisco, at Stanford University, and at both the Los Angeles and Berkeley campuses of the University of California. Reference was also made to remnants of the Josiah Keep Collection at Mills College. In addition, specimens were collected at several west coast localities.

I wish to thank Dr. Leo George Hertlein, California Academy of Sciences, for making the collection of that institution available to me, for his hours of assistance, and for his suggestions. I am particularly indebted to Dr. William M. Ingram, Mills College, who inspired and guided the entire project.

My sincere thanks are also extended to the following individuals: Dr. W. A. Hilton, Pomona College; Dr. Willis P. Popenoe and Dr. Ulysses S. Grant, University of California at Los Angeles; Dr. Howard Hill, Curator of Zoology, Los Angeles County Museum; Dr. A. Myra Keen, Stanford University; Frank R. Rogers, Photographer, and Veronica Sexton, Librarian, California Academy of Sciences.

ECOLOGY OF THE NASSARIIDAE

Habitat

The Nassariidae are distributed throughout the marine waters of the world; the only portions of the globe where they have not been found is in the icy seas near the poles. However, they occur principally in tropical and subtropical waters. Most of the species are littoral, although a few live at considerable depths.

These gastropods are called mud snails, since many aggregate on mud flats and in the shallow water of bays and inlets. For example, I have collected *Nassarius tegula* in great numbers from the mud flats at Estero de Punta Banda, Lower California, and in lesser numbers from the flats of Anaheim and Alamitos

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bays, Southern California. I have taken *N. fossatus* from the flats at Anaheim Bay and MacGinitie (1935) reports this species from the flats at Elkhorn Slough, California. During low tide at Bay Farm Island, San Francisco Bay, I have seen the mud dotted with hundreds of *N. obsoletus*.

Behavior

The Nassariidae are active molluscs. They burrow readily, leaving a small mound of dirt which discloses their location. By means of their large, muscular foot, they plow through the mud, usually in search of food, the bifurcated foot leaving a characteristic trail behind.

Since most Nassariidae are burrowers, they avoid desiccation and can often escape from predators. Also, this burrowing habit, as well as the habit of living in sheltered bays, isolates these gastropods from the destructive action of waves and currents.

There is disagreement regarding the actions of the Nassariidae when left exposed by the tide's recession, or perhaps some species react in an opposite manner from others. Tryon (1882) says that, when the tide goes out, *N. reticulatus* buries itself in the sand to await the water's return. MacGinitie (1935) also states that the Nassariidae burrow when exposed. However, according to Rogers (1939), when the tide recedes, *N. trivittatus* comes up from beneath the sand and crawls toward the water.

Food and Feeding

Because the Nassariidae are carnivorous, they are pests to oyster growers. They bore into oyster shells, insert their extensible proboscis, and eat out the contents. An adult *Nassarius* bores through a 3-year-old oyster shell in 8 hours, but the younger gastropods are far more destructive, selecting the delicate shells of the very young oysters and piercing 15 or 20 in rapid succession. A month-old oyster is eaten in half an hour.

These snails also bore through shells of other pelecypods and gastropods, devouring the soft parts. At Estero de Punta Banda, I have seen live specimens of the large Bubble Shell, *Bullaria gouldiana*, covered with hungry *Nassarius tegula* apparently enjoying a fresh meal at the expense of their ill-fated neighbor. Several authors suggest that the Nassariidae even attack their own kind.

The Nassariidae are voracious scavengers. They have often been reported climbing into lobster pots for the dead bait. I have seen hordes of *N. tegula* feeding on putrid animal matter in the shallow pools at Estero de Punta Banda.

MacGinitie (1935) describes the eating method of *N. fossatus*. When a snail discovers a piece of food, it turns over and lies shell downward with its foot held high and tightly wrapped about the food, which is thus hidden while the animal devours it. He also (1949) describes the powerful sucking action of its mouth, located at the end of the long proboscis which can be extended 1.5 inches. These snails cling so tightly to a bit of food that they allow themselves to be lifted entirely out of the water before relaxing their hold.

That the keen olfactory sense of these gastropods is their principal means of finding food is thoroughly established by interesting experiments recorded by Cooke (1895) and MacGinitie (1935).

Predators

The Nassariidae are, in turn, eaten by larger animals. Keep (1935) tells of removing *Nassarius* from the stomach of a fish. According to Tryon (1883), in Italy *Nassarius mutabilis* is prepared for human consumption. Several authors report *Nassarius* shells inhabited by hermit crabs. At Estero de Punta Banda, I have seen many *N. tegula* possessed by hermit crabs. At Bay Farm Island, numbers of *N. obsoletus* had been invaded by these crabs. Of the Nassariidae in the California Academy of Sciences collection, there are shells of *N. catallus*, *N. cerritensis*, and *N. insculptus* retain-

ing crab remnants. This evidence seems to indicate these species are preyed upon, or at least have their shells appropriated, by hermit crabs.

Some Nassariidae seem adapted to escape particular enemies. A striking behavior was observed by Bauer (Flattely, 1922). He watched *Nassarius reticulatus* flee a pursuing starfish, *Astropecten bispinosus*. The snail fled by curious leaps, using its foot as a lever, in the manner of a cockle. The movement was such a convulsive one that Bauer found it difficult to follow, but it appeared to be a kind of somersault. This escaping reflex occurred only when the gastropod was directly touched by the starfish. Also, the snail's body was not everywhere equally sensitive to this stimulus; only when the two tails of the mollusc's foot were touched was the reaction produced. Bauer was unable to induce the reflex either mechanically or chemically—only through the medium of a starfish.

Oviposition

The Nassariidae are dioecious. They lay eggs in strong, leathery capsules, the capsules of each species having a characteristic appearance. Each capsule contains a varying number of ova, and there is competition among the embryos within the capsule, so that only a very small percentage survive.

According to Tryon (1883), *Nassarius reticulatus* deposits its spawn on various objects, such as *Zostera* leaves, which are out of the water only during spring tides. These egg-capsules are tiny, compressed pouches, supported by a tiny stalk and arranged in closely overlapping rows. The larvae remain within the capsule for several days after hatching before escaping through a small aperture at the top of the capsule.

Tryon (1882) says *N. obsoletus* lays its ova-capsules during April and May. These capsules are attached singly and are crowded together. During May, I have seen thousands of capsules of *obsoletus* at Bay Farm Island. The capsules were attached to pilings, to living and dead gastropods and pelecypods, to rocks, driftwood, and the inside of an old rubber tire.

Ricketts and Calvin (1948) state that ovipositing *N. fossatus* may be found among eelgrass during late summer. Burch (1945) says *fossatus* is not seasonal; he records their spawning in Anaheim Bay during January.

The egg-laying process of *N. fossatus* has been observed and recorded in detail by MacGinitie (1931).

Adaptation to Environment

The recurved anterior canal of most *Nassarius* shells aids those gastropods living on a muddy substrate. This structure protects the animal's respiratory organ, the siphon, which projects above the mud, thus allowing the snail to breathe while concealed in the sediment.

In many cases, the color of *Nassarius* shells, by blending with the environment, protects the inhabitants from discovery. For example, the shell of *N. obsoletus* is dark brown or blackish, so it is not easily seen on the mud. The body of this mollusc, too, is a dark color, like the muddy sand in which the animal lives. *N. obsoletus* is made even more inconspicuous by its somewhat latticed shell surface. Particles of substrate collect in the irregularities of this surface and conceal the shell.

TAXONOMIC STUDY

Family *NASSARIIDAE*

These gastropods usually possess a more or less ovate shell with a raised spire and a short, recurved anterior canal. Typically, a callus covers the inner lip, often spreading over the body whorl.

Characteristically, these molluscs develop a long siphon and a broad foot. In almost all species, the foot is divided posteriorly into two slender appendages; the only west coast species lacking such bifurcation is *Nassarius obsoletus*. Eyes are present on the outer bases of the tentacles. The operculum is

usually corneous, ovoid in shape, with plain or serrated margins. The lingual teeth are arched and pectinate; the uncini possess a basal horn and, occasionally, intermediate serrations.

Genus NASSARIUS Duméril, 1805

Arcularia Martini, Neves Syst. Conch. Cab., 2: 18, 1771.

Nassarius Duméril, Zool. Analyt., p. 166, 1806 [genus without species]; Froriep's translation, p. 167, 1806, only species added, *Buccinum arcularia* [*fide* Iredale, Malac. Soc. London, Proc. 12: 80, 81, 82, 1916].

Arcularia Link, Beschr. Nat. Samml. Univ. Rostock, p. 126, 1807.

? *Eione* Risso, Hist. Nat. Eur. Mérid., 4: 171, 1826; Herrmannsen, Indicis Gen. Malac., 1: 414, 1847.

"*Nassa* Martini" H. and A. Adams, Gen. Rec. Moll., 1: 116, 1853.

TYPE SPECIES: *Buccinum arcularia* Linnaeus, Syst. Nat., ed. 10, p. 737, 1758; figured by Reeve, Conch. Icon., Vol. 8, *Nassa*, pl. 4, figs. 25a, 25b, 1853.

TYPE LOCALITY: Philippine Islands; Recent (Reeve, 1853).

Since the Nassariidae are molluscs which have been known and collected for many years, they have a long and varied taxonomic history. Martini's genus *Arcularia*, 1771, seems to be the earliest name in the literature. This author named *Arcularia* as a section of *Galeodes* or *Semicassis*, which he called a subgenus of *Cassis*. He included *Arcularia major* Martini in his species list. This species is said to be synonymous with *Buccinum arcularia* Linnaeus. Consequently, *Buccinum arcularia*, by absolute tautonomy, becomes the genotype. However, Martini's work is generally disregarded as not being consistently binomial.

Arcularia Link, 1807, has been used by some authors for this genus. However, it is an absolute synonym of *Nassarius* Duméril.

Dall (1917, 1921) and Oldroyd (1927) used the family name Alectrionidae and the generic name *Alectrion* Montfort, 1810. The type of Montfort's genus was *Buccinum papillosum* Linnaeus, a mollusc which differs greatly from *B. arcularia*, the type of *Nassarius*. The shell of *B. papillosum* is heavy and large, with a thick outer lip, a prominent posterior canal, and a somewhat narrow but heavy callus. As *B. papillosum* differs so much from the west coast species, the use of *Alectrion* for these species has been rejected.

Although Woodring (1946) doubts the validity of using *Nassarius* and prefers "*Nassa*," the opinion of recent authors seems to be to accept *Nassarius* Duméril as a substitute for *Nassa* Lamarck. Froriep (1806), in his translation of Duméril, assigned only the species *Buccinum arcularia* Linnaeus to *Nassarius*. Consequently, this species becomes the genotype by monotypy.

The author's opinion is that *Nassarius* Duméril is the preferable name to use until a comprehensive taxonomic revision of the family is completed.

The question of the valid subgeneric divisions of *Nassarius* also awaits further study. Various subgenera have been proposed, but many are arbitrary and difficult to apply. A general practice has been to use *Schizopyga* for *N. fossatus*, *N. perpinguis*, *N. californianus*, *N. cerritensis*, and *N. mendicus*. *N. tegula* is close to the type of the genus and is considered to represent *Nassarius* proper. The entire family needs careful evaluation before valid subgenera can be recognized. Since only a limited geographic area is covered in the present paper, the author has entirely excluded subgeneric classification.

Twelve species and two subspecies of *Nassarius* live in the area between Cape San Lucas and Cape Flattery. Some of these species are among the earliest molluscs known to science from this area. Only species found living in this area at present are considered here, although many members of the family are also common as fossils.

Nassarius is the only genus of this family found within the area considered here.

KEY TO THE WEST COAST SPECIES OF NASSARIIDAE

A. Orange callus spreading over body whorl ..... *Nassarius fossatus*
Orange callus absent ..... **B**

B. Length of shell greater than width of body whorl ..... **C**
Length of shell approximately equal to width of body whorl ..... *N. corpulentus*

C. With distinct groove over dorsum of anterior canal ..... **D**
Without distinct groove over dorsum of anterior canal ..... *N. obsoletus*

D. Narrow shelf just at sutures ..... **E**
Shelf at sutures absent ..... **F**

E. Raised ribs formed by axial lines present within aperture; shell sturdy; maximum length, 26 mm. ..... *N. perpinguis*
Raised ribs within aperture usually absent; shell thin; maximum length, 37 mm. ..... *N. californianus*

F. Callus spreading at least slightly over body whorl ..... **G**
Callus definitely delimited, not spreading over body whorl ..... **I**

G. Transverse sculpture of definite nodes **H**
Transverse sculpture of ribs which do not form definite nodes ..... *N. cerritensis*

H. Shell white or with brown spiral bands on body whorl; length approximately 13 mm. ..... *N. tegula tiarula*
Shell dark brown or purplish without color bands; length approximately 18 mm. ..... *N. tegula*

I. Outer lip sharp and thin; shell slender and elongate ..... **J**
Outer lip swollen; shell not slender and elongate ..... **K**

J. Nodes prominent on body whorl ..... *N. mendicus cooperi*
Nodes absent or poorly developed on body whorl ..... *N. mendicus*

K. Anterior canal somewhat long and curved; length 18 to 27 mm.; whorls angular ..... *N. pagodus*
Anterior canal short ..... **L**

L. Transverse sculpture prominent on all whorls ..... **M**
Transverse sculpture prominent only on upper whorls; dominant sculpture of numerous extremely faint spiral lines encircling all whorls ..... *N. insculptus*

M. Transverse sculpture forming nodes on body whorl; axial sculpture of impressed lines ..... *N. versicolor*
Transverse sculpture not forming nodes on any whorls; axial sculpture of raised lines ..... *N. catallus*

Nassarius fossatus (Gould)

Pl. I, Fig. 2

Buccinum elegans Reeve, Zool. Soc. London, Proc. (10): 199, 1843, [non] *Buccinum elegans* Costa, 1822.

Buccinum fossatum Gould, Boston Soc. Nat. Hist., Proc. 3: 152, 1849.

Nassa reevei A. Adams, Zool. Soc. London, Proc. for 1851: 109 [nomen novum for *Buccinum elegans* Reeve].

Nassa fossata Gould, Gabb, Geol. Survey Calif., Paleontol. 2: 74, 1868-69; Cooper, Amer. Jour. Conch. 6: 68, 1870; Keep, West Coast Shells, p. 36, fig. 16, 1893; Packard, Calif. Univ., Pubs., Zool. 18(13): 303, 1918.

Nassa (*Tritia*) *fossata* Gould, Tryon, Man. Conch. I, 4: 55, pl. 17, figs. 316, 317, 1882.

Alectrion fossata Gould, Chace, E. P., Nautilus 29(11): 130, 1916; Jordan, South. Calif. Acad. Sci., Bul. 23: 149, 1924; Johnson and Snook, Seashore Animals of the Pacific Coast, p. 513, fig. 530, 1927.

Alectrion fossatus Gould, Dall, U. S. Natl. Mus., Proc. 51: 575, 1917; Oldroyd, I. S., Wash. Univ., Puget Sound Biol. Sta. Pubs. 4: 95, pl. 22, figs. 3, 4, 1924.

Alectrion (*Schizopyga*) *fossata* Gould, Dall, U. S. Natl. Mus., Bul. 112: 102, 1921; Waterfall, Calif. Univ., Pubs., Geol. Sci. 18: 78, 1929.

Alectrion (*Schizopyga*) *fossatus* Gould, Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser.

Geol. Sci. 2(1): 264, pl. 26, figs. 1, 3, 5, 7, 9, 1927.

Nassarius (*Schizopyga*) *fossatus* (Gould), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 675, pl. 26, figs. 55, 56, 1931; Keep, West Coast Shells, p. 229, fig. 220, 1935.

Nassarius fossatus (Gould), Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 107–173, 1936; Smith and Gordon, Calif. Acad. Sci., Proc. IV, 26(8): 187, 1948.

"*Nassa*" *fossata*, Woodring, U. S. Geol. Survey, Prof. Paper 207: 73, 1946.

TYPE LOCALITY: Puget Sound at mouth of Columbia River (Oldroyd, 1927).

DESCRIPTION: Maximum length, 48 mm.; average length, 36 mm.; usually 8 whorls, last whorl pronouncedly ventricose; spiral and transverse ridges over shell surface; conspicuous orange callus on inner lip, spreading over body whorl; outer lip sharp, denticulated by ends of spiral ridges; sutures distinct, deeply impressed; mature specimens often with prominent posterior canal; anterior canal broad, short, sharply reflected; deep fossa at base of body whorl; main shell color ashen.

This species was named *Buccinum elegans* by Reeve, but since *Buccinum elegans* was preoccupied for a fossil species, A. Adams changed the name to *Nassa reevei*, which falls before Gould's prior name of *Buccinum fossatum*.

RECENT GEOGRAPHIC RANGE: Sitka, Alaska, to Cedros Island, Lower California.

HABITAT: Common on mud flats; rare in 10 or 15 fathoms.

Nassarius perpinguis (Hinds)

Pl. II, Figs. 4, 5

Nassa perpinguis Hinds, Zool. Voy. Sulphur, Mollusca, p. 36, pl. 9, figs. 12, 13, 1844; Carpenter, Brit. Assoc. Adv. Sci., Rpt. for 1863: 662, 1864; Tryon, Man. Conch. I, 4: 56, pl. 17, fig. 319, 1882; Keep, West Coast Shells, p. 38, fig. 19, 1893.

Nassa intastriata Conrad, U. S. House of Representatives, House Document 129: 17, July 1855, reprinted by Dall, U. S. Geol. Survey, Prof. Paper 59: 169, 1909.

Nassa interstriata Conrad, U. S. Pacific Railroad Survey 5: 327, 1856, correction in spelling of "intastriata."

Nassa perpinguis Gould, Keep, West Amer. Shells, p. 184, fig. 186, 1904.

Nassa perpinguis var. *bifasciata* Berry, Nautilus 22: 39, 1908.

Alectrion perpinguis Gould, Chace, E. P., Nautilus 29: 130, 1916.

Alectrion perpinguis Hinds, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917; Oldroyd, I. S., Wash. Univ., Puget Sound Biol. Sta. Pubs. 4: 96, pl. 22, fig. 5, 1924; Jordan, South. Calif. Acad. Sci., Bul. 23: 149, 1924; Johnson and Snook, Seashore Animals of the Pacific Coast, p. 513, fig. 532, 1927.

Alectrion (*Schizopyga*) *perpinguis* Hinds, Dall, U. S. Natl. Mus., Bul. 112: 103, 1921; Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 266, pl. 26, fig. 11, 1927.

Nassarius perpinguis (Hinds), Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 114, 1936; Smith and Gordon, Calif. Acad. Sci., Proc. IV, 26(8): 187, 1948.

Nassarius (*Schizopyga*) *perpinguis* (Hinds), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 673, pl. 26, figs. 51, 52, 1931; Keep, West Coast Shells, p. 228, fig. 218, 1935.

"*Nassa*" *perpinguis*, Woodring, U. S. Geol. Survey, Prof. Paper 207: 73, 1946.

TYPE SPECIMEN: Zoological Museum, Copenhagen (Oldroyd, 1927).

TYPE LOCALITIES: Of *perpinguis*, Magdalena Bay, Lower California (Recent); of *intastriata* Conrad, Santa Barbara, California (Pleistocene); of *bifasciata*, San Pedro, California (Recent) (Grant and Gale, 1931).

DESCRIPTION: Maximum length, 26 mm.; average length, about 22 mm.; usually 7 rounded whorls; many sharp, spiral ridges crossed by posteriorly sloping transverse ridges, giving shell reticulate surface; transverse

ornamentation typically most prominent on upper whorls, spiral most prominent on lower whorls; transverse ridges sometimes nearly obsolete on body whorl; inner lip with slight callus; outer lip plain, thin; aperture about 1/3 length of shell, ridged inside by spiral sculpture; sutures distinct, usually with narrow shelf just at sutures; short, curved anterior canal; conspicuous groove at base of body whorl; columella spirally ornamented, often with groove on upper part; shell color ashen.

Some specimens of *N. perpinguis* possess one or two bands of darker color around the middle of each whorl (Pl. II, Fig. 4). Berry (1908) named these specimens variety *bifasciata*. However, these shells are now considered merely color variations of no taxonomic significance.

RECENT GEOGRAPHIC RANGE: Puget Sound, Washington, to Magdalena Bay, Lower California.

HABITAT: Common in 10 to 50 fathoms, in sand.

Nassarius californianus (Conrad)

Pl. II, Fig. 6

Schizopyga californiana Conrad, Acad. Nat. Sci. Phila., Proc. for 1856: 315, 1856; Carpenter, Brit. Assoc. Adv. Sci., Rpt. for 1863: 593, 1864.

Schizopyga californica Conrad, Tryon, Man. Conch. I, 4: 55, pl. 3, fig. 32, 1882.

Nassa californiana Conrad, Keep, West Amer. Shells, p. 185, 1904; Arnold, Calif. Acad. Sci., Mem. 3: 231, [non] pl. 4, fig. 3, 1903.

Alectrion (*Schizopyga*) *californiana* Conrad, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917; Dall, U. S. Natl. Mus., Bul. 112: 102, pl. 11, fig. 4, 1921.

Alectrion (*Schizopyga*) *californianus* Conrad, Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 264, pl. 26, fig. 13, 1927.

Alectrion californiana Conrad, Jordan, South. Calif. Acad. Sci., Bul. 23: 149, 1924.

Nassarius (*Schizopyga*) *californianus* (Conrad), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 672, pl. 26, fig. 49, 1931; Keep, West Coast Shells, p. 228, 1935.

Nassarius californianus (Conrad), Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 114, 1936; Smith and Gordon, Calif. Acad. Sci., Proc. IV, 26(8): 187, 1948.

TYPE LOCALITY: Santa Clara, California (Oldroyd, 1927).

There is much confusion concerning *N. californianus*. Woodring (1946) says the species is based on fossil material which has been lost, so the status of this species is uncertain until a neotype is designated. The locality of this type material was near Santa Clara, California, presumably Pliocene. Woodring believes this fossil material probably was the species later described as "*Nassa*" *moraniana*. "*N.*" *moraniana* is an extinct Pliocene species not known to occur in the Pleistocene. He claims the Recent species identified by Dall as *californiana* is not *moraniana* and evidently is not *californiana* and thus needs a new name. Grant and Gale (1931) state, "Whether the shell figured by Dall (1921) as *californianus* is identical with Conrad's presumed Miocene species cannot be said at the present time." Grant and Gale (1931) further state that "Arnold's figure in his San Pedro memoir (1903) is not typical of Conrad's species, and may be of an undescribed variety or even a new species." Woodring (1946) proposes a new name, "*Nassa*" *delosi*, for Arnold's figured *californiana*.

The shell figured by Dall (1921) represents the species generally recognized today as *Nassarius californianus*. Consequently, Dall's species is the basis of the following description.

DESCRIPTION: Maximum length, 37 mm.; average length, 23–25 mm.; 6 or 7 rounded whorls; spiral ribs crossed by transverse ridges; spiral and transverse sculpture about equally well developed, giving shell reticulate surface; sutures well defined; aperture about 1/3 length of shell, with ribs usually not apparent within; outer lip plain; callus usu-

ally quite thin; basal groove deep; posterior canal absent; closely resembles *N. perpinguis*, but almost twice as large.

RECENT GEOGRAPHIC RANGE: Oregon coast to San Ignacio Lagoon, Lower California.

HABITAT: 30 to 40 fathoms, in mud and sand; rare.

Nassarius tegula (Reeve)

Pl. II, Fig. 8

Nassa tegula Reeve, Conch. Icon. 8: 98, pl. 15, fig. 98, 1853; Carpenter, Brit. Assoc. Adv. Sci., Rpt. for 1863: 662, 1864; Tryon, Man. Conch. I, 4: 39, pl. 13, figs. 166, 167, 1882; Keep, West Coast Shells, p. 37, fig. 17, 1893; Stearns, U. S. Natl. Mus., Proc. 17: 180, 1894; Arnold, Calif. Acad. Sci., Mem. 3: 235, 1903.

Arcularia tegula Reeve, Dall, U. S. Natl. Mus., Proc. 51: 577, 1917.

Alectrion (*Zeuxis*) *tegula* Reeve, Dall, U. S. Natl. Mus., Bul. 112: 103, 1921; Waterfall, Cal. Univ., Pubs., Geol. Sci. 18: 78, 1929.

Alectrion tegula (Reeve), Jordan, South. Calif. Acad. Sci., Bul. 23: 149, 1924; Johnson and Snook, Seashore Animals of the Pacific Coast, p. 513, fig. 533, 1927.

Alectrion (*Schizopyga*) *tegulus* Reeve, Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 267, pl. 26, fig. 10, 1927.

Nassarius tegulus, Keen, West North Amer. Mar. Moll., p. 41, 1937.

Nassarius (*Nassarius*) *tegula* (Reeve), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 671, pl. 26, fig. 43, 1931; Keep, West Coast Shells, p. 228, fig. 217, 1935; Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 114, 1936.

"*Nassa*" *tegula* Woodring, U. S. Geol. Survey, Prof. Paper 207: 73, 1946.

TYPE SPECIMEN: Cuming Museum, London, England (Oldroyd, 1927).

TYPE LOCALITY: Habitat unknown (Reeve, 1853); California or Lower California (Oldroyd, 1927).

DESCRIPTION: Maximum length, 21 mm.; average length, 16–18 mm.; typically 6 whorls; spire short and sharp; low axial folds becoming nodose at shoulders of whorls; sometimes faint spiral ridges; typically, body whorl smooth below nodes; prominent callus on parietal wall of body whorl; outer lip often thickened externally, denticulate; sutures distinct; aperture usually slightly greater than 1/3 length of shell with small canal at each end; groove at base of body whorl; much color variation, frequently purplish brown.

RECENT GEOGRAPHIC RANGE: San Francisco, California, to Lower California.

HABITAT: Common on mud flats.

Nassarius tegula tiarula (Kiener) new comb.

Pl. I, Fig. 4

Buccinum tiarula Kiener, Spéc. Gén. et Icon. des Coq. Viv. (2): 111, pl. 30, fig. 4, 1834.

Nassa tiarula Kiener, Tryon, Man. Conch. I, 4: 41, pl. 12, figs. 174–178, 1882.

Arcularia tiarula Kiener, Dall, U. S. Natl. Mus., Proc. 51: 577, 1917.

Nassarius tiarulus (Kiener), Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 114, 1936.

DESCRIPTION: Maximum length, 18 mm.; average length, 13–15 mm.; shell small, strong; spire short, sharp; typically 7 or 8 whorls; body whorl about ½ length of shell; ornamentation of low axial folds, nodose at shoulders of whorls; body whorl usually smooth below nodes; sometimes faint spiral ribs; noticeable callus on inner lip; outer lip usually thickened; aperture slightly greater than 1/3 length of shell, denticulate within; sutures impressed, wavy; groove at base of body whorl not prominent; anterior canal short, recurved; posterior canal small; much color variation; basic color usually whitish or faintly yellow, often with varying numbers of brown spiral bands, particularly on body whorl; often highly polished.

This species is exceedingly variable, particularly in color and ornamentation. Some specimens possess no spiral threads, while

others have such threads running around the entire shell, even on the body whorl, which is typically smooth. The transverse ridges and nodes are seldom the same in number or in size.

This mollusc was described by Kiener (1834) as a separate species, while Stearns (1894), Grant and Gale (1931), and others have put it into synonymy with *Nassarius tegula*. In my opinion, however, *N. tiarula* is a subspecies of *N. tegula*. *N. tiarula* has a more southern range than does *N. tegula*, *tiarula* ranging from Panama to Lower California, while *tegula* ranges from Lower California as far north as San Francisco. Also, *tiarula* has a smaller shell and finer sculpture than does *tegula*. The color of the two forms is usually different; *tiarula* is generally white or yellowish, while *tegula* is usually purplish brown. Of course, variations from the typical form of each are often seen, particularly where their geographic ranges overlap.

RECENT GEOGRAPHIC RANGE: Lower California to Panama.

HABITAT: Mud flats or in a few fathoms.

Nassarius cerritensis (Arnold)

Pl. II, Fig. 7

Nassa cerritensis Arnold, Calif. Acad. Sci., Mem. 3: 231, pl. 4, fig. 1, 1903.

Alectrion cerritensis Arnold, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917; Jordan, South. Calif. Acad. Sci., Bul. 23: 149, 1924.

Alectrion (*Schizopyga*) *cerritensis* Arnold, Dall, U. S. Natl. Mus., Bul. 112: 102, 1921; Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci., 2(1): 266, 1927.

Nassarius (*Schizopyga*) *cerritensis* (Arnold), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 675, 1931.

Nassarius cerritensis (Arnold), Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 114, 1936.

"*Nassa*" *cerritensis* Arnold, Woodring, U. S. Geol. Survey, Prof. Paper 207, pl. 35, figs. 16–19, 1946.

TYPE SPECIMEN: U. S. National Museum, No. 162,553 (Grant and Gale, 1931).

TYPE LOCALITY: Los Cerritos (Signal Hill), Los Angeles County (Pleistocene).

DESCRIPTION: Maximum length, 20 mm.; average length, about 17 mm.; 7 to 8 somewhat rounded whorls; several prominent, rounded, transverse ridges, not forming nodes, crossed by several sharp, raised, spiral lines, giving reticulate surface; cancellation not as prominent as in *N. californianus* or *N. perpinguis;* inner lip smooth with thin callus spreading somewhat onto body whorl; outer lip thickened internally by denticulated ridge; sutures wavy; deep groove below body whorl; short, broad, recurved anterior canal.

RECENT GEOGRAPHIC RANGE: Lower California to Gulf of California.

Dall (1917) claims this species is found living from San Pedro to the Gulf of California. However, Burch (1945) says, "It is a common fossil in local Pleistocene deposits but seems to be of the southern [Recent] fauna. The consensus of opinion regarding this species is stated by Dr. George Willett briefly, 'Probably lower Californian.' " Woodring (1946) states that, according to numerous specimens in the National Museum, a small race of *cerritensis* or a closely related species is living along the Lower California coast at Point Abreojos and Ballenas Bay and in the Gulf of California at Guaymas.

I agree that *N. cerritensis* does not belong to the Recent fauna of the west coast of California, although it apparently lives on the Lower California coast. I have never found any specimens living on our coast, nor have I located any specific record of its being taken alive on this coast. Statements in the literature of occurrences at Long Beach (Grant and Gale, 1931) and Santa Monica (Keen, 1937) probably refer to fossil collections.

HABITAT: 20 to 30 fathoms.

Nassarius mendicus (Gould)

Pl. I, Fig. 3

Nassa mendica Gould, Boston Soc. Nat. Hist.,

Proc. 3: 155, 1851; Carpenter, Brit. Assoc. Adv. Sci., Rpt. for 1863: 662, 1864; Tryon, Man. Conch. IV, 4: 56, pl. 17, figs. 320–323, 1882; Keep, West Coast Shells, p. 37, [non] fig. 18, 1893; Arnold, Calif. Acad. Sci., Mem. 3: 233, 1903.

Nassa woodwardi Forbes, Zool. Soc. London, Proc. for 1850: 273, pl. 11, fig. 3, 1850.

Nassa gibbsii W. Cooper, U. S. Pacific Railroad Rpts., Sup. to 1(3): 371, 1859.

Alectrion mendicus Gould, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917; Oldroyd, I. S., Wash. Univ., Puget Sound Biol. Sta., Pubs. 4: 95, pl. 22, fig. 6, 1924; Jordan, South. Calif. Acad. Sci., Bul. 23: 149, 1924.

Alectrion (*Schizopyga*) *mendica* Gould, Dall, U. S. Natl. Mus., Bul. 112: 102, 1921; Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 265, pl. 26, fig. 2, [non] figs. 6, 14, 1927.

Alectrion cooperi var. *woodwardi* Forbes, Oldroyd, I. S., U. S. Natl. Mus., Proc. 65(22): 12, 1925.

Alectrion mendica (Gould), Johnson and Snook, Seashore Animals of the Pacific Coast, p. 513, [non] fig. 531, 1927.

Nassarius (*Schizopyga*) *mendicus* (Gould), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 674, pl. 26, fig. 54 [immature], 1931; Keep, West Coast Shells, p. 229, [non] fig. 219, 1935.

Nassarius mendicus (Gould), Jordan, Stanford Univ., Dept. Geol. Contrib. 1(4): 114, 1936; Smith and Gordon, Calif. Acad. Sci., Proc. IV, 26(8): 187, 1948.

"*Nassa*" *mendica*, Woodring, U. S. Geol. Survey, Prof. Paper 207: 73, 1946.

TYPE SPECIMEN: Boston Society of Natural History (Oldroyd, 1927).

TYPE LOCALITY: Nisqually, Port Discovery, Puget Sound (Oldroyd, 1927). According to Burch (1945), A. M. Keen states that, "The holotype label of *N. mendicus* at the National Museum gives the type locality as Straits of Fuca."

DESCRIPTION: Maximum length, 25 mm.; average length, about 14 mm.; shell elongate; spire elevated; 6 to 7 whorls; length of body whorl almost half the shell length; many fine, raised, spiral threads crossed by fewer, coarser, transverse ridges; definitely delimited white callus on inner lip, not spreading over body whorl; outer lip sharp, simple; line of about 10 raised ribs within aperture, not reaching edge of lip; definite groove at base of body whorl; anterior canal broad, short, slightly reflected; posterior canal typically absent; shell color usually reddish brown or light ashen.

RECENT GEOGRAPHIC RANGE: Forrester Island, Alaska, to Magdalena Bay, Lower California.

HABITAT: 5 to 40 fathoms, in sand.

Nassarius mendicus cooperi (Forbes)

Pl. I, Fig. 1

Nassa cooperi Forbes, Zool. Soc. London, Proc. for 1850: 273, pl. 11, fig. 4, 1850; Carpenter, Brit. Assoc. Adv. Sci., Rpt. for 1863: 662, 1864; Keep, West Coast Shells, p. 37, figs. 18, 1893.

Nassa mendica Gould var. *cooperi* Forbes, Dall, U. S. Natl. Mus., Proc. 19: 377, pl. 33, fig. 9, 1897; Arnold, Calif. Acad. Sci., Mem. 3: 234, 1903; Berry, Nautilus 22: 38, 1908.

Alectrion mendica cooperi Forbes, Chace, E. P., Nautilus 29(11): 130, 1916.

Alectrion cooperi Forbes, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917; Oldroyd, I. S., Wash. Univ., Pubs., Puget Sound Biol. Sta. 4: 96, 1924.

Alectrion (*Schizopyga*) *cooperi* Forbes, Dall, U. S. Natl. Mus., Bul. 112: 102, 1921; Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 265, pl. 26, fig. 8, 1927.

Nassarius (*Schizopyga*) *mendicus cooperi* (Forbes), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 674, pl. 26, figs. 40, 50, 1931; Keep, West Coast Shells, p. 229, fig. 219, 1935.

Nassarius (*Schizopyga*) *cooperi* (Forbes), Vokes, Nautilus 50(2): 47, 1936.

"*Nassa*" *mendica cooperi*, Woodring, U. S.

Geol. Survey, Prof. Paper 207: 73, pl. 34, fig. 12, 1946.

Nassarius cooperi (Forbes), Smith and Gordon, Calif. Acad. Sci., Proc. IV, 26(8): 187, 1948.

TYPE SPECIMEN: British Museum? (Oldroyd, 1927).

TYPE LOCALITY: Said to be "Sandwich Islands," probably a ballast shell (Oldroyd, 1927).

DESCRIPTION: The preceding description of *Nassarius mendicus* may be applied to *cooperi* except that the transverse sculpture is more pronounced on the latter form; the longitudinal ridges become actual nodes in the middle of the whorls on *cooperi*.

Several authors place *N. cooperi* in synonymy with *N. mendicus*. However, I am inclined to call *cooperi* a subspecies. It is true that these two forms occur together at many points along the Pacific coast. However, most authors give Alaska as the northernmost range of *mendicus* and Puget Sound as the northernmost range of *cooperi*. Thus, *cooperi* seems to be a more southern form. It is also true that several workers record collections of specimens showing perfect intergradation between the two forms. However, I believe that the difference between the typical *mendicus*, having relatively smooth whorls completely lacking nodes, and the prominently tubercled *cooperi* is sufficient to separate *cooperi* as a subspecies of *mendicus*.

RECENT GEOGRAPHIC RANGE: Puget Sound, Washington, to San Diego, California.

HABITAT: 3 to 24 fathoms, in sand.

Nassarius pagodus (Reeve)

Pl. I, Fig. 7

Triton pagodus Reeve, Conch. Icon. 2: 97, pl. 20, fig. 97, 1843.

Buccinum decussatum Kiener, Spéc. Gén. et Icon. des Coq. Viv. (2): 109, pl. 30, fig. 3, 1834.

Nassa pagoda Reeve, Tryon, Man. Conch. I, 4: 45, pl. 14, figs. 226–228, 1882; Pilsbry and Lowe, Acad. Nat. Sci. Phila., Proc. 84: 115, 1932.

Alectrion pagoda Reeve, Dall, U. S. Natl. Mus. Proc. 51: 576, 1917.

Nassarius pagodus Reeve, Strong, Hanna, and Hertlein, Calif. Acad. Sci., Proc. IV, 21(10): 119, 1933.

TYPE SPECIMEN: In Cuming collection, Museum Norris? (Reeve, 1844).

TYPE LOCALITY: Bay of Montija, West Columbia (Reeve, 1844).

DESCRIPTION: Maximum length, 27 mm.; average length, about 23 mm.; usually 8 whorls; prominent transverse ridges forming angular nodes in middle of whorls; fine spiral threads; inner lip with definitely margined callus, not spreading over body whorl; prominent tooth on upper part of columella; outer lip swollen; somewhat long, recurved anterior canal; wide, deep groove at base of body whorl; aperture almost half length of shell, denticulate within; shell color varies, often white or yellowish or variously banded with brown.

RECENT GEOGRAPHIC RANGE: Cape San Lucas, Lower California, to Panama.

HABITAT: 3 to 40 fathoms; also on mud flats.

Nassarius versicolor (C. B. Adams)

Pl. I, Fig. 5

Nassa versicolor C. B. Adams, N. Y. Lyceum Nat. Hist., Ann. 5: 66 [pagination of separate], 1852; Cooper, J. G., Calif. Acad. Sci., Proc. II, 5: 45, 1895.

Nassa versicolor var. *striatula* C. B. Adams, N. Y. Lyceum Nat. Hist., Ann. 5: 66, 1852.

Nassa (*Hima*) *versicolor* C. B. Adams, Tryon, Man. Conch. I, 4: 50, pl. 15, fig. 270, 1882.

Alectrion versicolor C. B. Adams, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917.

Nassarius versicolor (C. B. Adams), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 677, 1931.

Nassarius versicolor (A. Adams), Jordan, Stan-

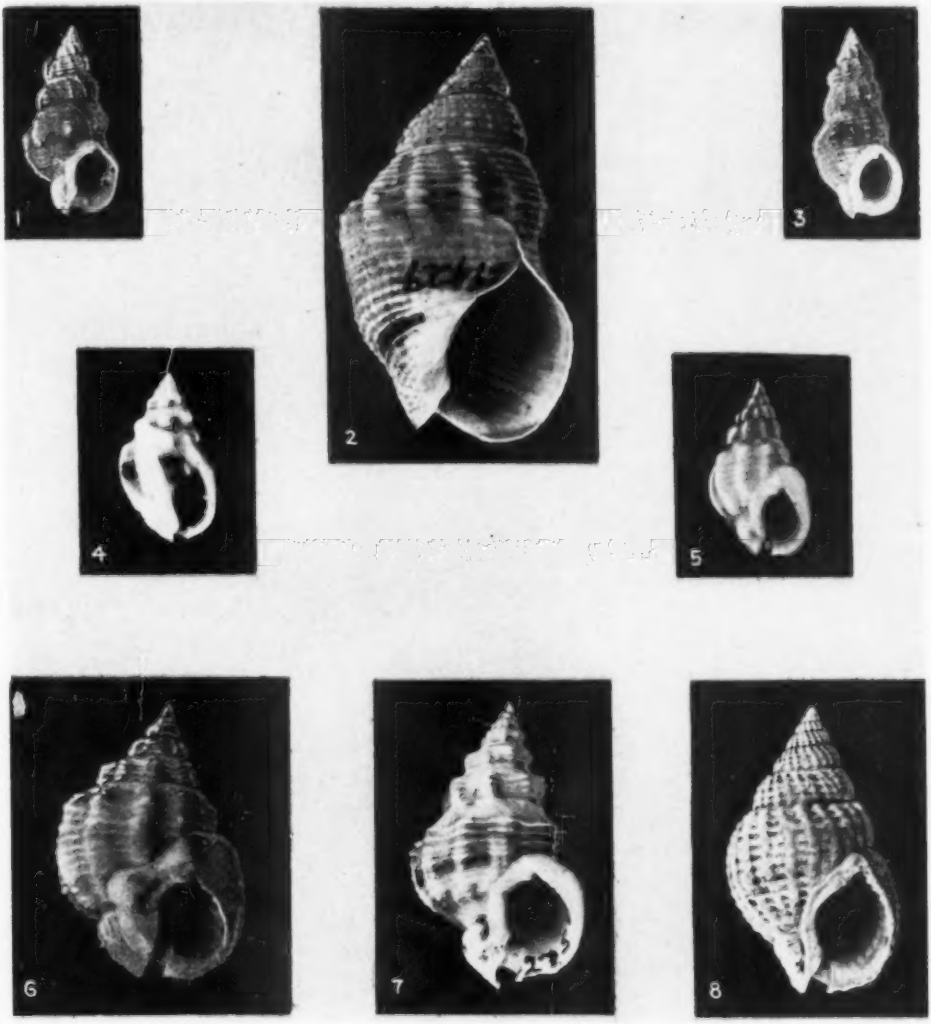

PLATE I

(All measurements are actual dimensions of specimens photographed)

FIG. 1. *Nassarius mendicus cooperi* (Forbes); Santa Rosa Island, California. Calif. Acad. Sci. Loc. 23681. Length: 15 mm. Max. diameter: 7.9 mm.

FIG. 2. *Nassarius fossatus* (Gould); Long Beach, California. Calif. Acad. Sci. Loc. 29429. Length: 37.9 mm. Max. diameter: 22.5 mm.

FIG. 3. *Nassarius mendicus* (Gould); 20 to 30 fathoms in Monterey Bay, California. Calif. Acad. Sci. Loc. 24147. Length: 14.6 mm. Max. diameter: 6.8 mm.

FIG. 4. *Nassarius tegula tiarula* (Kiener); Puerto Escondido, Gulf of California. Calif. Acad. Sci. Loc. 23805. Length: 13.0 mm. Max. diameter: 7.3 mm.

FIG. 5. *Nassarius versicolor* (C. B. Adams); 12 to 15 fathoms in Port Parker, Costa Rica. Calif. Acad. Sci. Loc. 17924. Length: 13.8 mm. Max. diameter: 7.9 mm.

FIG. 6. *Nassarius corpulentus* (C. B. Adams); Margarita Island, Lower California. Calif. Acad. Sci. Loc. 701 (H. Hemphill Coll.). Length: 19.2 mm. Max. diameter: 13.5 mm.

FIG. 7. *Nassarius pagodus* (Reeve); near Mazatlan, Mexico. Calif. Acad. Sci. Loc. 27581. Length: 27.3 mm. Max. diameter: 17.3 mm.

FIG. 8. *Nassarius catallus* (Dall); 35 to 40 fathoms in the Gulf of Chiriqui, Panama. Calif. Acad. Sci. Loc. 17986. Length: 20.8 mm. Max. diameter: 12.5 mm.

ford Univ., Dept. Geol. Contrib. 1(4): 114, 1936.

TYPE LOCALITY: Panama; Recent (Grant and Gale, 1931).

DESCRIPTION: Maximum length, 17 mm.; average length, 13–15 mm.; usually 7 whorls; length of body whorl almost half shell length; sculpture of numerous, evenly spaced spiral grooves, crossed by fewer prominent transverse ridges, forming nodules at tops of first 3 whorls; sculpture faint on upper whorls; inner lip with definitely delimited callus, not spreading over body whorl; outer lip somewhat thickened; aperture denticulate within; sutures distinct, wavy; shallow groove at base of body whorl; anterior canal short, broad, curved; sometimes a small posterior canal with a distinct ridge below it on columella; color usually white with scattered brown spots or bands; much variation in color and amount of sculpture.

RECENT GEOGRAPHIC RANGE: Magdalena Bay, Lower California, to Payta, Peru.

HABITAT: 3 to 45 fathoms.

Nassarius catallus (Dall) new comb.

Pl. I, Fig. 8

Alectrion (*Hima*) *catallus* Dall, Harvard Univ., Mus. Compar. Zool., Bul. 43(6): 307, pl. 11, fig. 11, 1908.

Alectrion catallus Dall, U. S. Natl. Mus., Proc. 51: 576, 1917.

TYPE SPECIMEN: U. S. National Museum (Dall, 1908).

TYPE LOCALITY: U. S. S. "Albatross" Station 3355, Gulf of Panama (Dall, 1908).

DESCRIPTION: Shell solid; spire acute; usually 8 whorls; sharp reticulate sculpture of many axial riblets and larger transverse ridges; sutures very distinct, not channeled; callus definitely margined; aperture rounded-quadrate with about 19 rather distinct axial ribs within; outer lip with strong varix; usually 1 or 2 elongate pustules on columella below posterior canal; anterior canal short, recurved; deep sulcus at base of body whorl.

RECENT GEOGRAPHIC RANGE: Off San Miguel Island, California, to Panama.

HABITAT: 20 to 182 fathoms; rare.

Nassarius insculptus (Carpenter)

Pl. II, Figs. 1, 3

Nassa insculpta Carpenter, Brit. Assoc. Adv. Sci., Rpt. for 1863: 662, 1864; Arnold, Calif. Acad. Sci., Mem. 3: 233, 1903.

Nassa (*Zeuxis*) *insculpta* Carpenter, Tryon, Man. Conch. I, 4: 38, pl. 12, fig. 154, 1882.

Alectrion insculptus Carpenter, Dall, U. S. Natl. Mus., Proc. 51: 576, 1917.

Alectrion insculptus eupleura Dall, U. S. Natl. Mus., Proc. 51: 576, 1917.

Alectrion (*Zeuxis*) *insculptus* Carpenter, Dall, U. S. Natl. Mus., Bul. 112: 103, 1921.

Alectrion (*Zeuxis*) *insculptus eupleura* Dall, U. S. Natl. Mus., Bul. 112: 103, 1921.

Alectrion (*Schizopyga*) *insculptus* Carpenter, Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 267, pl. 26, fig. 12, 1927.

Alectrion (*Schizopyga*) *insculptus eupleura* Dall, Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 267, 1927.

Nassarius insculptus (Carpenter), Grant and Gale, San Diego Soc. Nat. Hist., Mem. 1: 677, 1931; Keen, A. M., West North Amer. Mar. Moll., p. 41, 1937; Smith and Gordon, Calif. Acad. Sci., Proc. IV, 26(8): 187, 1948.

Nassarius eupleurus, Keen, A. M., West North Amer. Mar. Moll., p. 41, 1937.

"*Nassa*" *insculpta*, Woodring, Bramlette, and Kew, U. S. Geol. Survey, Prof. Paper 207: 73, pl. 29, fig. 27, 1946.

TYPE SPECIMENS: Of *insculptus:* State Collection, University of California (Oldroyd, 1927). Of *eupleura:* U. S. National Museum, No. 209046 (Dall, 1917).

TYPE LOCALITIES: Of *insculptus:* 3 to 40 fathoms off Catalina Island, California (Recent). Of *eupleura:* Not stated by Dall, but somewhere between San Simeon, California, and Cedros Island, Lower California (Grant and Gale, 1931).

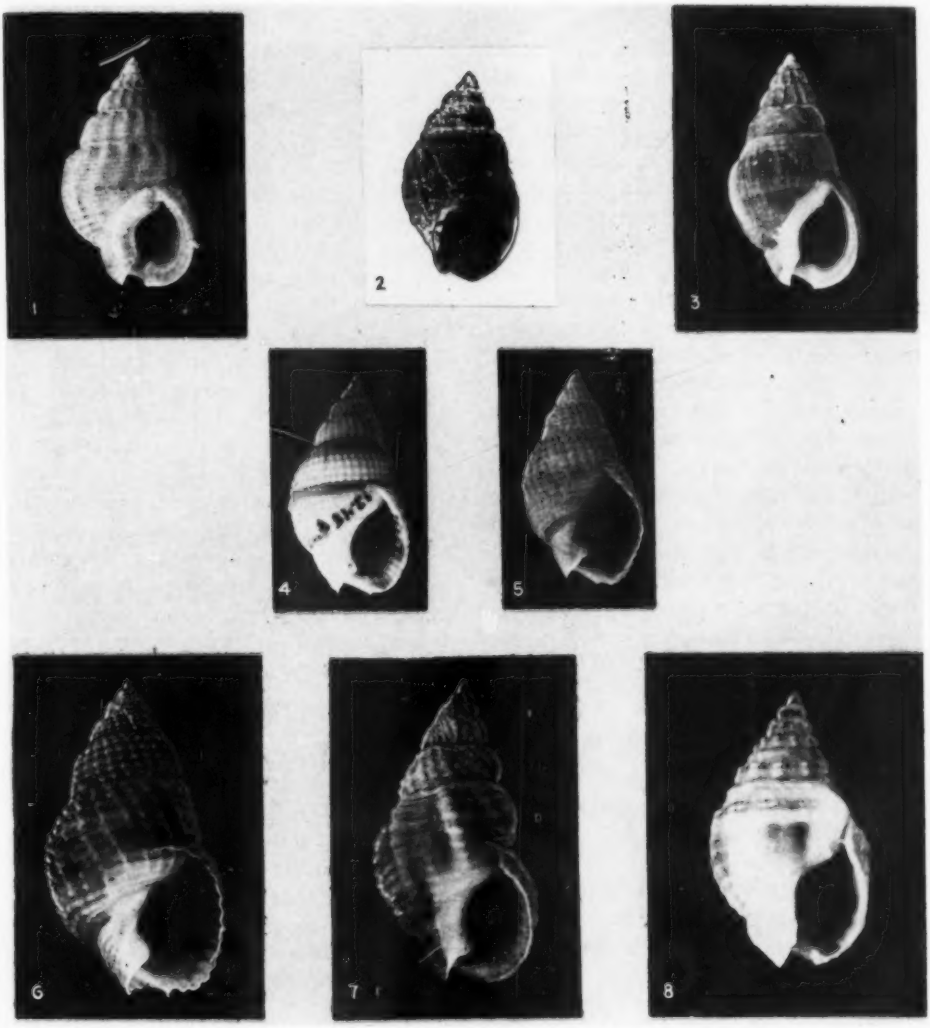

PLATE II

(All measurements are actual dimensions of specimens photographed)

FIG. 1. *Nassarius insculptus* (Carpenter); Cortez Banks, California. The variation possessing transverse ridges on the body whorl, named *eupleura* by Dall (1917). Calif. Acad. Sci. Loc. 27602. Length: 16.9 mm. Max. diameter: 9.6 mm.

FIG. 2. *Nassarius obsoletus* (Say); Alameda, California. Introduced with oysters from eastern states. Calif. Acad. Sci. Loc. 15159.

FIG. 3. *Nassarius insculptus* (Carpenter); Cortez Banks, California. Calif. Acad. Sci. Loc. 27602. Length: 23.0 mm. Max. diameter: 13.0 mm.

FIG. 4. *Nassarius perpinguis* (Hinds); San Diego, California. The banded variation called *bifusciata* by Berry (1908). Calif. Acad. Sci. Loc. 12458. Length: 16.8 mm. Max. diameter: 9.4 mm.

FIG. 5. *Nassarius perpinguis* (Hinds); San Pedro, California. Calif. Acad. Sci. Loc. 25459. Length: 19.2 mm. Max. diameter: 10.9 mm.

FIG. 6. *Nassarius californianus* (Conrad); 30 fathoms off Point Bonito, California. Calif. Acad. Sci. Loc. 28592. Length: 30.7 mm. Max. diameter: 16.7 mm.

FIG. 7. *Nassarius cerritensis* (Arnold); 20 to 30 fathoms in San Bartolome Bay, Lower California. Calif. Acad. Sci. Loc. 32294. Length: 21.8 mm. Max. diameter: 11.8 mm.

FIG. 8. *Nassarius tegula* (Reeve); San Diego, California. Calif. Acad. Sci. Loc. 24820. Length: 18.8 mm. Max. diameter: 11.7 mm.

DESCRIPTION: Maximum length, 23 mm.; average length, 18–22 mm.; usually 7 whorls; numerous fine, spiral furrows, most prominent on lower portion of body whorl; typically, no transverse sculpturing except on last few whorls; definitely margined callus on inner lip, not spreading over body whorl; spiral sculpture usually apparent through callus; outer lip thickened by slightly denticulate ridge; columella often separated from body whorl by deep, narrow groove; anterior canal short, broad, curved.

Typical *N. insculptus* possesses no transverse sculpture on the body whorl or the penultimate whorl. In my opinion, the form *eupleura*, in which the axial ribs continue onto the body whorl, is a variation of no taxonomic value. I have seen collections containing specimens grading from the typical *insculptus*, with no longitudinal ridges on the body whorl, to specimens possessing conspicuous transverse ribs on the body whorl. The ribbed form cannot be called a subspecies because its geographic range coincides with that of the typical form.

RECENT GEOGRAPHIC RANGE: Point Arena, California, to Cedros Island, Lower California.

HABITAT: 10 to 200 fathoms, in mud, sand, gravel; rare.

Nassarius obsoletus (Say)

Pl. II, Fig. 2

Nassa obsoleta Say, Acad. Nat. Sci. Phila., Jour. 2: 232, 1822

Nassa (*Ilyanassa*) *obsoleta* Say, Tryon, Man. Conch. I, 4: 60, pl. 18, figs. 237–249, 1882.

Ilyanassa obsoleta Say, Dall, Nautilus 21: 91, 1907; U. S. Natl. Mus., Proc. 51: 578, 1917.

Alectrion (*Ilyanassa*) *obsoleta* Say, Dall, U. S. Natl. Mus., Bul. 112: 103, 1921; Oldroyd, I. S., Stanford Univ., Pubs., Univ. Ser. Geol. Sci. 2(1): 269, pl. 26, fig. 15, 1927.

Nassarius (*Ilyanassa*) *obsoletus* Say, Keep, West Coast Shells, p. 230, 1935.

Nassarius obsoletus, Keen, A. M., West North Amer. Mar. Moll., p. 41, 1937.

TYPE SPECIMEN: Philadelphia Academy of Natural Sciences (Oldroyd, 1927).

TYPE LOCALITY: East coast (Oldroyd, 1927).

DESCRIPTION: Maximum length, 25 mm.; average length, about 20 mm.; shell solid; 6 or 7 convex whorls; sutures simple, not deeply impressed; body whorl longer than length of spire; apex blunt, usually broken; numerous faint spiral ribs crossed at an angle by slightly raised transverse ridges; cancellate sculpture sometimes giving granulated appearance to shell surface, particularly on upper whorls; outer lip plain or slightly thickened at edge; aperture often lineated within by elevated, interrupted spiral lines; thin white or brownish callus on inner lip, spreading only slightly onto body whorl; posterior canal typically absent, if present a faint groove; anterior canal but a slight notch; no groove at base of body whorl; shell dark reddish brown, blackish, or lighter brown, sometimes tinged with olive green or banded with lighter color.

This species is called the "Worn-Out Dog Whelk" because of its eroded appearance. Rarely are perfect shells found, since the spire is usually broken at the apex. This species lacks the bifurcated foot typical of most Nassariidae.

RECENT GEOGRAPHIC RANGE: On West Coast: Boundry Bay, British Columbia; San Francisco, Oakland, Alameda, and Palo Alto, California. Introduced from east coast with oyster seed.

HABITAT: Flourishing on oyster beds and mud flats.

Nassarius corpulentus (C. B. Adams)

Pl. I, Fig. 6

Nassa corpulenta C. B. Adams, N. Y. Lyceum Nat. Hist., Ann. 5: 284, 529 [pagination of separate: 60, 305], 1852; Stearns, U. S. Natl. Mus., Proc. 17: 181, 1894; Pilsbry and Lowe, Acad. Nat. Sci. Phila., Proc. 84: 115, 1932.

Nassarius corpulenta C. B. Adams, Bales, Nautilus 52: 45, 1938.

DESCRIPTION: Maximum length, 20 mm.; average length, about 17 mm.; 7 or 8 convex whorls; body whorl longer than half length of shell; body whorl almost as wide as length of shell; sutures impressed, somewhat wavy; several prominent transverse ridges, most noticeable on first 3 whorls, forming small nodes near sutures; many fine, evenly-spaced, raised, spiral threads; outer lip considerably thickened; row of denticles within aperture; columella concave, covered with heavy callus, which is often denticulate; posterior canal faintly indicated on some specimens; anterior canal short, rather broad, slightly reflected; deep groove at base of body whorl; shell whitish or ashen, often with few brown bands encircling body whorl.

RECENT GEOGRAPHIC RANGE: Cape San Lucas, Lower California, to Colombia.

Species of Doubtful Occurrence or Uncertain Systematic Position

Several Nassariidae reportedly have been collected within the area treated in this paper which, in my opinion, do not belong to this fauna. These species are discussed below.

Nassarius nodicinctus (A. Adams)

Dall (1921) states that *N. nodicinctus* ranges from San Diego, California, to Panama and the Galapagos Islands. This range has been copied by succeeding authors, such as Oldroyd (1927) and Keen (1937). However, these authors cite no actual specimens taken as far north as San Diego. In the collections consulted, there were no specimens from the west coast of North America; all were from the Galapagos Islands. I have located no mention, other than Dall's report, of specimens found in this area. In collecting along the California coast, I have never discovered *N. nodicinctus*. Furthermore, the type locality of this species is in the Galapagos. For these reasons, I believe Dall's record from San Diego is a mistake perpetuated by subsequent conchologists and that this species should be excluded from the faunal record for this area.

Nassarius noduliferus (Philippi)

N. noduliferus is also reported by Dall (1921) to occur at San Diego, ranging from San Diego to the Gulf of California. Here again, Oldroyd (1927) and Keen (1937) record the same range. However, in this case too, I have found no record, either in the collections or the literature, of actual specimens from the west coast. Also, the type locality of *noduliferus* is in the China Seas. In my opinion, this species definitely is not a member of the west coast fauna.

Nassarius nodiferus (Powys)

N. nodiferus, recognized by Carpenter (1864) as living in Panama and the Galapagos, has been confused with *N. noduliferus*. *N. nodiferus* is not a west coast form either; I have found no record of its being taken from this coast, and I have never collected it here myself.

Alectrion tschudii (Troschel)

If Dall's (1917) report of a species named *Alectrion tschudii*, ranging from Cedros Island, Lower California, to Peru, is correct, this mollusc should be included in this paper, since it would occur within the area from Cape San Lucas to Cape Flattery. However, in my opinion, this name should be discarded entirely. In all the literature, Dall's reference to this species is the only one I have located. Dr. Howard Hill, Curator of Zoology at the Los Angeles County Museum, writes (personal communication) that *A. tschudii* is a name given the juvenile form of *Nassarius dentiferus*. Since *N. dentiferus* lives in Mexico, Panama, and Peru, not ranging as far north as Cape San Lucas, it is not considered in this paper.

Alectrion lirata (Dunker)

A. lirata should merely be mentioned in this list. Bonnot (1935) reports that a shipment of Japanese seed oysters was inspected at Elkhorn Slough. The *Nassarius* specimens therein were identified by Dr. Paul Bartsch of the U. S. National Museum as *Alectrion lirata* (Dunker). However, this is the only reference to this species' being found on our coast, so I assume that, unlike *N. obsoletus*, it has not become established in this area.

Nassarius onchodes (Dall)

Dall (1917) described a species of Nassariidae which he named *Alectrion onchodes*, ranging from Cedros Island, Lower California, to Panama. This species was never figured. In the collections, I found no example of this mollusc. Although Jordan (1936) reports *N. onchodes* from the Pleistocene of Magdalena Bay, Lower California, I have discovered no other record of its being collected either living or as a fossil. Consequently, the position of this species remains uncertain.

Nassarius mendicus indisputabilis (Oldroyd)

The systematic status of *N. mendicus indisputabilis* is also problematic. This mollusc was figured and named as a subspecies of *N. mendicus* by Oldroyd (1927), but no description of it was given. According to Grant and Gale (1931), *indisputabilis* is of no value. However, although I was able to locate only two specimens identified as *indisputabilis*, they do differ from typical *mendicus*, as well as from the subspecies *cooperi*. The shells of *indisputabilis* are about 8 millimeters in length, smaller than *mendicus* or *cooperi*. The sculpture of *indisputabilis* is sharper, the axial threads being more prominent than on either *mendicus* or *cooperi*. Unlike either *mendicus* or *cooperi*, the transverse and axial ornamentation is about equally well developed and distinct on all whorls. Both the basal groove and the anterior canal of *indisputabilis* are larger in relation to shell size than on *mendicus* or *cooperi*. *N. indisputabilis* seems to have a more northern range than *mendicus* or *cooperi;* the specimens I examined, housed at the California Academy of Sciences, were from Annette Island, Alaska.

Further to confuse the question, the California Academy of Sciences specimens of *indisputabilis* are much closer to Oldroyd's (1927) Figure 14, representing *mendicus*, than to Oldroyd's (1927) Figure 4, which supposedly shows *indisputabilis*. Until a description of *indisputabilis* is published and more specimens are collected, the true position of this form cannot be determined.

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Iodine Content of Some Marine Algae[1]

MADELON R. GRIMM[2]

THE LITERATURE ON IODINE and iodide content of marine algae has been reviewed by Fritsch (1945), Chapman (1950), and Smith (1951). To their extensive bibliographies, the contributions of Turrentine (1912) and Cameron (1914, 1915) may be added.

Since many of the early investigators were interested primarily in the economic aspects of the algae, they generally disregarded the suitability of the species studied for laboratory use. For example, their interests were concerned with the extraction and utilization of iodine for dietary and medicinal purposes. The use of this substance in fertilizer resources was also promoted.

In recent years the use of iodine in tracer studies with its many applications necessitates an expanded spectrum of available species of algae to determine which organisms lend themselves to further laboratory study in this field. As far as can be determined, very little work has been done to ascertain the manner in which algae are able to accumulate iodine and retain it against enormous concentration gradients. In search of suitable experimental organisms for such studies and under the assumption that such organisms should both accumulate iodine and lend themselves to modified microbiological procedures, numerous species of marine algae were examined.

The samples studied were collected alive in the field and air dried in the laboratories of the collectors (see footnotes of Table 1). Upon receipt, these collections were cleaned and redried at room temperature. A weighed amount (usually 1 gm.) was incinerated to a black ash in a porcelain crucible over a Bunsen burner. The ash was pulverized and mixed with 5 milliliters of distilled water and the soluble portion separated by centrifugation. The supernatant was shaken up with 1 milliliter chloroform, 2 milliliters hydrogen peroxide, and 1 milliliter glacial acetic acid. After several minutes, the presence of iodine was manifested by a pink to purple color in the chloroform layer, the intensity of the color increasing with iodine concentration. When the nonchloroform layer retained a brownish tinge, more hydrogen peroxide and acetic acid were added until decolorization occurred, and the mixture was reshaken. The color of the chloroform layer was compared to color standards containing known concentrations of iodine in chloroform. This method is assumed to be a satisfactory means of estimating the iodide content of the algal ash when iodide is present in concentrations of over 30 parts per million.

Quantitative estimations for iodine obtained in this investigation are presented in Table 1 and are expressed in milligrams per gram of dry weight of alga and in parts per million. Unused portions of the collections

[1] Based in part upon data included in a thesis submitted to Cornell University in partial fulfillment of the requirements for the degree of Master of Science. This investigation was performed under the supervision of Dr. Maxwell S. Doty and Dr. Walter C. Muenscher and supported in part by grants from Cornell University and Graduate Research Funds of Northwestern University. Manuscript received February 20, 1952.

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TABLE 1
IODINE CONTENT OF VARIOUS SPECIES OF ALGAE

SPECIES TESTED	COLLECTION*	SOURCE†	MG. I_2/ GM. ALGA	PARTS PER MILLION
Chlorophyta				
Anadyomene stellata (Wulf.) C. Ag.	B 49–2134	B	0.156	160
Avrainvillea longicaulis (Kuetz.) Murray & Boodle	B	B	0.024	20
Bryopsis plumosa (Hudson) C. Ag.	G	M	0.195	200
Chaetomorpha linum (Mueller) Kuetz.	G	M	0	0
	B 49–2203	B	0.110	100
Codium intertextum Collins & Hervey	B 49–2139	B	0.300	300
Codium setchellii Gardner	H	O	0.078	80
Dictyosphaeria cavernosa (Førsk.) Boergesen	D 8118	H	0	0
	D 8584	H	0.039	40
Halimeda monile (Ellis & Solander) Lamour.	B 49–2103	B	0.02	20
Ulva expansa (Setch.) Setch. & Gard.	H 1054	O	0.059	60
Phaeophyta				
Agarum cribrosum (Mertens) Bory	G 249	M	0.078	80
Alaria marginata Post. & Rupr.	H	O	0.059	60
Ascophyllum nodosum (L.) Le Jolis	G	M	0.156	160
Asperococcus echinatus (Mertens) Grev.	G 258	M	0.056	60
Chorda filum (L.) Lamour.	G	M	0.227	230
Chordaria flagelliformis (Mueller) C. Ag.	G 283	M	0.313	310
Cladostephus verticillatus (Light.) C. Ag.	G 277	M	1.094	1090
Coilodesme bulligera Stroemfelt	H 1019	O	0.234	230
Coilodesme californica (Rupr.) Kjellm.	H 1074, 1075	O	0.25	250
Cystoseira osmundacea (Menzies) C. Ag.	H	O	0.117	120
Desmarestia aculeata (L.) Lamour.	G 287	M	2.5	2500
Desmarestia munda Setch. & Gard.	H 7689	O	0.469	470
Dictyopteris plagiogramma (Mont.) Vickers	B 49–2081	B	0.234	230
	D 8561	H	0.02	20
Dictyosiphon foeniculaceus (Hudson) Grev.	G	M	0.284	280
Dictyota dichotoma (Hudson) Lamour.	B 49–2206	B	0.013	10
Ectocarpus siliculosus (Dillwyn) Lyngbye	G	M	0.087	90
Elachistea fucicola (Velley) Aresch.	G	M	0.195	200
Fucus evanescens C. Ag.	G 278	M	0	0
	H 1088	O	0.078	80
Fucus evanescens f. *oregonensis* Gard.	H 1077	O	0.078	80
Fucus furcatus C. Ag.	H 1078	O	0.117	120
Fucus spiralis L.	G	M	0.120	120
Fucus vesiculosus L.	G	M	0.052	50
Haplogloia andersonii (Farlow) Levring	H 1064	O	1.25	1250
Hedophyllum sessile (C. Ag.) Setch.	H	O	1.25	1250
Laminaria agardhii Kjellm.	G 268	M		
Young thallus			3.125	3130
Blade			2.083	2080
Stipe			1.563	1560
Haptera and rhizoids			5.0	5000
Laminaria andersonii Eaton in Hervey	H	O		
Blades			0.938	940
Upper stipe			5.0	5000
Laminaria digitata (L.) Edm.	G 279	M	1.041	1040
Laminaria saccharina (L.) Lamour.	H 1065	O		
Lower blades			1.25	1250
Laminaria sinclairii (Aresch.) Anderson	H 1058	O		
Blades			5.0	5000
Haptera and rhizoids			1.875	1880
Stipe			3.75	3750
Lessoniopsis littoralis (Tilden) Reinke	H	O	0.117	120
Macrocystis integrifolia Bory	H	O		
Blades			0.938	940
Axis of branch			0.117	120

TABLE 1—continued

SPECIES TESTED	COLLECTION*	SOURCE†	MG. I_2/ GM. ALGA	PARTS PER MILLION
Mesogloia divaricata (C. Ag.) Kuetz.	G	M	0.240	240
Nereocystis luetkeana (Mertens) Post. & Rupr.	H	O		
Air bladder			0.938	940
Sterile blades			0.625	630
Pelvetiopsis limitata (Setch.) Gard.	H	O	0.156	160
Postelsia palmaeformis Rupr.	H	O		
Blades			1.25	1250
Stipe			0.469	470
Holdfast			1.25	1250
Pterygophora californica Rupr.	H	O	0.029	30
Ralfsia clavata (Carm.) Crouan	G	M	0.087	90
Sargassum sp.	D 8572	H	0.02	20
Sargassum filipendula C. Ag.	G	M	0.156	160
Sargassum kjellmanianum Yendo	H 1067	O	0.02	20
Sargassum natans (L.) J. Meyen	B 49–2067	B	0.059	60
Sargassum obtusifolium J. Ag.	D 8114	H	0.029	30
Scytosiphon bullosus Saunders	H 1238	O	0.020	20
Soranthera ulvoidea Post. & Rupr.	H 1074	O	0.234	230
Sphacelaria cirrhosa (Roth) C. Ag.	G	M	0.314	310
Turbinaria tricostata Barton	B 49–2231	B	0.029	30
Rhodophyta				
Ahnfeltia concinna J. Ag.	H 1233	O	0.02	20
Ahnfeltia plicata (Hudson) Fries	H 1219	O	0.117	120
Amphiroa fragilissima (L.) Lamour.	B	B		
Coarse type			0.029	30
Fine type			0.156	160
Antithamnion uncinatum Gard.	H 1145	O	0.02	20
Asparagopsis hamifera (Hariot) Okamura	G 286	M	0.938	940
Asparagopsis sanfordiana Harvey	D 8663	H	1.25	1250
Laurencia spectabilis Post. & Rupr.	H 1107	O	0.078	80
Lophocladia trichoclados (Mertens) Schmitz	B 50–426	B	0.117	120
	B 49–2086	B	0.117	120
Asparagopsis taxiformis (Delile) Collins & Hervey	B 50–516	B	1.875	1875
Bostrychia scorpioides var. *montagnei* (Harvey) Post.	B 50–382	B	0.01	10
Botryglossum farlowianum (J. Ag.) De Toni	H	O	0.313	310
Callithamnion baileyi Harvey	G 203	M	0.234	230
Callithamnion pikeanum Harvey	H	O	0.039	40
Centroceras clavulatum (C. Ag.) Mont.	B 49–2151	B	0.234	230
Ceramium eatonianum (Farlow) De Toni	H	O	0.039	40
Corallina officinalis L.	G	M	0.02	20
Cryptopleura brevis Gard.	H 7680	O	0.029	30
Cryptosiphonia woodii J. Ag.	H 7685	O	0.117	120
Cystoclonium purpureum (Hudson) Batters	G 204, 270	M	trace	
Cystoclonium purpureum var. *cirrhosum* Harvey	G	M	0.039	40
Galaxaura obtusata (Ellis & Solander) Lamour.	B 49–2144	B	0.117	120
Galaxaura squalida Kjellm.	B 49–2070	B	0.059	60
Gelidium arborescens Gard.	H 1030	O	0.039	40
Gelidium corneum (Hudson) Lamour.	D 8709	H	0.029	30
Gelidium coulteri Harvey	H 1031, 7687	O	0.117	120
Gelidium crinale (Turner) Lamour.	G	M	0.117	120
Laurencia obtusa (Hudson) Lamour.				
Green phase	B 49–2195	B	0.039	40
Yellow phase	B 49–2194	B	0.117	120
Microcladia borealis Rupr.	H 1130	O	0.02	20
Odonthalia floccosa (Esper) Falken.	H 1133	O	0.078	80
Odonthalia washingtoniensis Kylin	H 1114	O	0.407	420
Phycodrys rubens (Hudson) Batters	G 285	M	0.313	310
Phyllophora membranifolia (Good. & Woodw.) J. Ag.	G	M	trace	trace
Plocamium pacificum Kylin	H 1191	O	0.029	30

TABLE 1—continued

SPECIES TESTED	COLLECTION*	SOURCE†	MG. I_2/ GM. ALGA	PARTS PER MILLION
Plumaria filicina (Farlow) Kuntz	H 7681	O	1.25	1250
Plumaria hypnoides (Harvey) Kuntz	H 1236	O	0.078	80
Plumaria sericea (Harvey) Rupr.	G	M	0.32	320
Polyides rotundus (Gmelin) Grev.	G	M	0.039	40
Polyneura latissima (Harvey) Kylin	H 1147	O	0.039	40
Polysiphonia elongata (Hudson) Harvey	G	M	trace	trace
Polysiphonia lanosa (L.) Tandy	G	M	0.438	440
Porphyra naiadum Anderson	H 1023	O	0.313	310
Pterochondria woodii (Harvey) Hollenberg	H 1148	O	0.078	80
Pterosiphonia bipinnata var. *robusta* (Gard.) Doty	H 1213	O	0.078	80
Rhodomela larix (Turner) C. Ag.	H 1033	O	0.156	160
Rhodymenia californica Kylin	H 1196	O	0.078	80
Spermothamnion turneri (Mertens) Aresch.	G	M	0.313	310
Zanardinula andersonii (J. Ag.) Papenfuss	H 7674	O	0.039	40
Zanardinula filiformis (Kylin) Papenfuss	H 7671	O	0.078	80
Zanardinula lanceolata (Harvey) De Toni	H 7672	O	0.02	20
	H 7673	O	0.059	60
Zanardinula lyallii (Harvey) De Toni	H 7675	O	0.117	120
	H 1050	O	0	0

* Collector: B, A. J. Bernatowicz; D, M. S. Doty; G, M. R. Grimm; H, L. Horowitz.
† Location: B, Bermuda; H, Hawaii; M, Woods Hole, Massachusetts; O, Cape Arago, Oregon.

treated remain for the most part in the herbaria of the various collectors. The collector and collector's number, where given, are shown in Table 1.

As is shown in Table 1, very little iodine was detected in the Chlorophyta, a finding which is in agreement with the data of other investigators. Phaeophyta such as *Laminaria* and *Desmarestia* had the highest concentrations of iodine. However, these genera are large forms difficult to maintain in the laboratory. *Asparagopsis* and *Plumaria*, both Rhodophyta, store iodine in considerable amounts and have the advantage of convenient cultural size.

A variation of iodine content was found in different thalli collected from the same locality. For example, one sample of *Laminaria agardhii* collected from Woods Hole showed no iodine while other specimens of the same species from the same vicinity showed an accumulation of 5,000 parts per million. Turrentine (1912) records similar variations with *L. saccharina*.

In a consideration of the iodine content of the same thallus, marked differences were noted by Turrentine (1912), Cameron (1915), and Black (1948). Fritsch (1945) reported that the greatest accumulation of iodine was in the actively growing cells at the base of the blade. Table 1 shows that the blades of *L. sinclairii* contained 5,000, haptera and rhizoids 1,880, and stipe 3,750 parts per million. Iodine determinations of other species of *Laminaria* provided similar results. Thus, in *Laminaria*, there appears to be an analogy between the activity of growth-regulating substances observed by Williams (1949) and the distribution and amounts of iodine present.

Table 1 also indicates that two phases of *Laurencia obtusa* contained different amounts of iodine—the yellow phase three times as much iodine as the green phase. The same appears to be true of two growth forms of *Amphiroa fragilissima*. A fine form contained more than five times as much iodine as a coarse form. A potential taxonomic use of the iodide test is suggested here as a supplement to the vague morphological criteria currently used in separating the infrageneric taxa of such genera.

The data presented indicate that *Asparagopsis* and *Plumaria* would be the most suitable species for further investigation. Their adap-

tation in this study allows the conjecture that they may be readily adaptable to methods of culture, iodine uptake, plant metabolism, and tracer studies.

A listing of algae which gave negative tests for iodine is presented here. These species represent approximately 50 per cent of all organisms tested. The source of the samples is as indicated in Table 1.

LIST OF SPECIES YIELDING NEGATIVE IODINE CONTENT

Cyanophyta

Calothrix confervicola (Roth) Ag. ex. Born. & Flah. . . . M
Lyngbya majuscula "(Dillwyn) Harvey ex. Gomot" . . . H

Chlorophyta

Boodlea composita (Harvey) Brand . . . H
Caulerpa crassifolia (C. Ag.) J. Ag. . . . B
Caulerpa peltata (Turner) Lamour. . . . B
Caulerpa racemosa var. *laetevirens* (Mont.) Weber-van Bosse . . . B
Caulerpa sertularioides (Gmelin) Howe . . . B
Caulerpa verticillata J. Ag. . . . B
Caulerpa webbiana Mont. . . . H
Chaetomorpha antennina (Bory) Kuetz. . . . H
Cladophora sp. . . . H
Cladophoropsis membranacea (C. Ag.) Børg. . . . B
Codium decorticatum (Woodw.) Howe . . . B
Codium fragile (Suringar) Hariot . . . O
Cympolia barbata (L.) Lamour. . . . B
Enteromorpha clathrata (Roth) Grev. . . . O
Enteromorpha intestinalis (L.) Link . . . O
Enteromorpha linza var. *flexicaulis* Doty . . O
Halimeda discoidea Decaisne . . . H
Monostroma grevillei (Thuret) Wittr. . . . O
Spongomorpha coalita (Rupr.) Collins . . . O
Udotea flabellum (Ellis & Solander) Howe . B
Ulva angusta Setch. & Gard. . . . O
Ulva fasciata Delile . . . H B
Ulva lactuca L. . . . M H
Ulva lobata (Kuetz.) Setch. & Gard. . . . O
Urospora penicilliformis (Roth) Aresch. . . . O
Vaucheria thuretii Woronin . . . O

Phaeophyta

Aegira virescens (Carm.) Setch. & Gard. . . M
Colpomenia sinuosa (Roth) Derbes & Solier . . . B
Costaria mertensii J. Ag. . . . O
Dictyopteris delicatula Lamour. . . . B
Dictyopteris justii Lamour. . . . B
Dictyota dentata Lamour. . . . B
Dictyota divaricata Lamour. . . . B
Dilophus guineensis (Kuetz.) J. Ag. . . . B
Ectocarpus indicus Sonder. . . . H
Egregia menziesii (Turner) Aresch. . . . O
Heterochordaria abietina (Rupr.) Setch. & Gard. . . . O
Hydroclathrus clathratus (Bory) Howe . . . B
Ilea fascia (Mueller) Fries . . . O M
Leathesia difformis (L.) Aresch. . . . M O
Padina commersonii Bory . . . H
Padina pavonia (L.) Gaillon . . . B
Padina sanctae-crucis Børg. . . . B
Pocockiella variegata (Lamour.) Papenfuss . B
Punctaria latifolia Grev. . . . M
Scytosiphon lomentaria (Lyngbye) J. Ag. . . . O M
Spatoglossum schroederi (Mertens) J. Ag. . . B
Zonaria zonalis (Lamour.) Howe . . . B

Rhodophyta

Acanthophora spicifera (Vahl) Børg. . . . B
Agardhiella tenera (J. Ag.) Schmitz . . . M
Bangia vermicularis Harvey . . . O
Callophyllis crenulata Setch. . . . O
Callophyllis megalocarpa Setch. & Gard. . . O
Ceramium pacificum (Collins) Kylin . . . O
Ceramium rubrum (Hudson) C. Ag. . . . O
Ceramium tenuissimum (Lyngbye) J. Ag. . . H
Champia parvula (C. Ag.) Harvey . . . M
Chrondrus crispus (L.) Stackh. . . . M
Chrondia sedifolia Harvey . . . M
Constantinea simplex Setch. . . . O
Cumagloia andersonii (Farlow) Setch. & Gard. . . . O
Delesseria decipiens J. Ag. . . . O
Dilsea californica (J. Ag.) Schmitz . . . O
Dumontia incrassata (Mueller) Lamour. . . M

Endocladia muricata (Harvey) J. Ag. . . . . O
Erythrophyllum delesserioides J. Ag. . . . . O
Eucheuma isiforme (C. Ag.) J. Ag. . . . . B
Farlowia mollis (Harvey & Bailey) Farlow & Setch. . . . . O
Galaxaura cylindrica (Ellis & Solander) Lamour. . . . . B
Galaxaura marginata (Ellis & Solander) Lamour. . . . . B
Halymenia formosa Kutz. . . . . H
Kylinia sp. . . . . H
Laurencia palisada Yamada. . . . . H
Liagora farinosa Lamour. . . . . B
Liagora maxima Butters. . . . . H
Liagora valida Harvey. . . . . B H
Lomentaria baileyana (Harvey) Farlow. . . M
Nemalion multifidum (Weber & Mohr) J. Ag. . . . . M
Opuntiella californica (Farlow) Kylin. . . . O
Petrocelis franciscana Setch. & Gard. . . . . O
Phyllophora brodaei (Turner) J. Ag. . . . . M
Polysiphonia collinsii Hollenberg. . . . . O
Polysiphonia fibrillosa Grev. . . . . M
Polysiphonia harveyi Bailey. . . . . M
Polysiphonia paniculata Mont. . . . . O
Polysiphonia variegata (C. Ag.) Zanardini. M
Porphyra nerocystis Anderson. . . . . O
Porphyra perforata J. Ag. . . . . O
Porphyra umbilicalis (L.) J. Ag. . . . . M
Porphyra variegata (Kjellm.) Hus. . . . . O
Pterosiphonia bipinnata (Post. & Rupr.) Falken. . . . . O
Rhodymenia pacifica Kylin. . . . . O
Rhodymenia palmata (L.) Grev. . . . . M
Schizymenia pacifica Kylin. . . . . O
Spyridia spinella Sander. . . . . H
Spyridia filamentosa (Wulf.) Harvey. . . . . M B
Thuretia borneti Vickers. . . . . B
Trichogloea subnuda Howe. . . . . H
Würdemannia miniata (Drap.) Feldman & Hamel. . . . . B

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News Notes

Scientific reconnaissance of Taongi and Bikar, in the Marshall Islands, has been started by a two-man field party of the Geological Survey, Secretary of the Interior Oscar L. Chapman has announced.

The geology will be mapped and hydrologic data will be collected by Charles G. Johnson, geologist, stationed at Tokyo, Japan. Vegetation studies will be made by Dr. F. Raymond Fosberg, botanist, Washington, D. C.

Knowledge of these atolls is expected to be of special significance because no scientific observations other than those made at a distance (from shipboard) have been recorded. They are reported never to have been inhabited and therefore should be almost entirely primitive and show less change from their original state as a result of human alterations. Further, they lie in the northernmost and driest part of the Marshalls so the vegetation is expected to differ somewhat from that found on atolls having heavier rainfall.

Inspection of Taongi and Bikar was scheduled as a major objective of the Marshall Islands reconnaissance made by F. Stearns MacNeil, Dr. Fosberg, and Theodore Arnow of the Geological Survey, from November, 1951, to April, 1952. During that time the field party examined more than 60 islands on the atolls of Utirik, Taka, Ailuk, Likiep, Jemo, Kwajalein, Ujelang, Wotho, Ujae, and Lae, but unfortunately a landing could not be made on Taongi or Bikar because of rough seas and strong currents.

The islands visited thus far range in size from tiny sand bars to islands nearly 3 miles long. Although it was not possible to study every island in every atoll, an attempt was made to visit the ones that would show the conditions on every part of an atoll. It is believed that most, if not all, of the stages in both the construction and the ultimate destruction of atoll islands were observed. Special attention was given to the types of materials comprising atoll sediments and to the shape and location of the deposits themselves. Direct observation of currents and waves actually transporting sediments contributed materially to an understanding of the mechanics involved in the construction of various physical forms.

Hydrologic studies indicate that a lens of fresh or relatively fresh ground water exists in each of the large islands of the atoll. This fresh-water lens is maintained by the accumulation of rain water in the clastic and reef deposits forming the island, and because of its lesser specific gravity, floats on the sea water saturating the rocks below it. The thickness, areal extent, and relative freshness of the lens are governed by the size of the island, the amount and distribution of rainfall, and the nature of the rocks containing the lens. Short-term observations were made of ground-water levels, tidal fluctuations in the ground-water bodies, and the quality of the water. Wells dug by natives and test holes dug during the investigation were utilized for the observations and, where conditions permitted, continuous records of water-level fluctuations were obtained by means of an automatic recording gauge. Ground-water levels and the relations between water-level fluctuations and ocean tides were determined from datum planes and tide gauges established by the geodetic control party. Quality-of-water studies included determinations of total salinity, chloride, *p*H, and hardness on samples from more than 100 wells and test holes. These determinations were made also for samples of ocean water, lagoon water, and rain water. The data obtained during the observations will be of value in the estimation of quantity and quality of water available in islands of atolls for present and future utilization.

Examination of the soils showed that, in most situations, there has been rather little alteration of the original sediments, the foraminiferal sand, the coral, and the algal fragments which make up the surface layers of the islands. Varying amounts of humus have been added to the surface layers, producing a greater or lesser darkening in color. In places, a thin layer of a form of peat has accumulated, and in excavations formerly used for taro gardens a dark-brown muck may be found. In many parts, burning of coconut trash and subsequent grass fires greatly reduce the amount

of humus added to the soil. An interesting phenomenon often noted is that of buried soils—layers in which a noticeable amount of humus has accumulated and which have then been buried to some depth by wind- or wave-transported sand or rubble. The frequency of these buried soils and of areas of completely fresh, unaltered coral sand and gravel, showing recent deposition or denudation, is an indication of the general instability of and domination by the sea, which are among the most outstanding features of the coral-atoll environment.

The vegetation growing on these soils is relatively simple, though a fair number of distinct types in various stages of development are evident. By far the greatest part of the area visited has been cleared and planted to coconuts, obliterating all evidence of the original vegetation. However, enough undisturbed spots were found so that one of the most significant contributions of the expedition may be toward the revealing of original conditions that prevailed on coral atolls, before the advent of man and the coconut. It is probable that on the older parts of the islands forests of great trees, up to 100 feet tall, were the dominant vegetation. On newer areas and those exposed to strong winds, the vegetation is scrubby, dense, tangled, and difficult to penetrate.

In general, the soils on the atolls visited did not appear to be infertile, but nevertheless only a few kinds of plants can be raised in gardens. The reason for failure of most kinds is not apparent, but it may be an excess of salt. The amount of ocean spray that blows in, especially on the windward sides of the islands, is undoubtedly a controlling factor in the development of both natural and imported vegetation. The salinity of the ground water also must exert an important influence where it lies at shallow depth.

The current research program is being carried out under the Pacific Geologic Mapping Program by cooperative agreement between the Geological Survey and the Corps of Engineers, United States Army. Johnson and Fosberg recently joined a new survey party of the 71st Engineer Survey Liaison Detachment at Wake Island. Their work on Taongi and Bikar will require about 3 weeks and will be done while United States Army Engineer personnel establish ground control for the preparation of topographic maps.

The Tenth General Assembly of the Union Radio-Scientifique Internationale was held in Sydney from August 11 to 21, 1952, under the presidency of Sir Edward Appleton, F.R.S. This was the first occasion on which an International Scientific Union has met in Australia or, in fact, in any country outside Europe and the United States. That the Union honored Australia by holding its Assembly there is tangible recognition of the outstanding contribution which Australian research workers have made in the field of radio science.

The meetings of the Australian and New Zealand Association for the Advancement of Science were held in Sydney from August 20 to 27. The Centenary of the University of Sydney was celebrated by appropriate ceremonies at this time.

Index

Acacia baileyana, 91
decurrens, 89, 90, 91
melanoxylon, 87, 89
podalyriaefoliae, 91
verniciflua, 89
Acer albopurascens, 288, 289, 290
buergerianum var. *formosanum*, 288, 290
caudatifolium, 290
caudatum, 290
duplicato-serrulatum, 293
hypoleucum, 288, 289, 290
itoanum, 288, 289
johnedwardianum, 293
kawakamii, 288, 290, 291
var. *taitonmontanum*, 288, 291
lanceolatum, 288
litseaefolium, 288, 289
matsumurae, var. *formosanum*, 293
morissonense, 290, 291
oblongum, 288, 289, 290
var. *itoanum*, 289
var. *microcarpum*, 289
oliverianum var. *microcarpum*, 292
var. *nakaharii*, 292
var. *trilobatum*, 291
ornatum var. *matsumurae*, 293
ovatifolium, 290, 291
palmatum matsumurae var. *spontaneum*, 293
palmatum var. *pubescens*, 288, 293
rubescens, 288, 291
serrulatum, 288, 292
taiton-montanum, 291
taiwanense, 293
trifidum var. *formosanum*, 290
tutcheri var. *shimadai*, 288, 291
Acizzia, 87
Acmena floribunda, 122
Aedes aegypti, 166, 167, 187
albolineatus, 167, 184, 187
albopictus, 166, 176
amesii, 158
arboricolus, 167, 185
aurotaeniatus, 166, 169
baisasi, 163
bambusicolus, 167, 186
boharti, 167, 185
brayi, 162
camposanus, 262
carmenti, 151, 153, 154
desmotes, 166, 170
eupoclamus, 262
fumidus, 160
gardnerii, 166, 172
hoogstraali, 167, 187
kabaenensis, 163
kochi, 151, 152, 154
laffooni, 167, 186
longirostris, 163
mediopunctatus var. *perplexus*, 167, 182
meronephada, 166, 174
paullusi, 166, 178
quasiscutellaris, 151, 152, 153, 154
scapularis, 262
scutellaris, 154, 180
Agathiphaga, 18–28
queenslandensis, 23–28
vitiensis, 18–23, 26–28
Aedes Mosquitoes of the Philippine Islands. II. Subgenera *Skusea*, *Christophersiomyia*, *Geoskusea*, *Rhinoskusea*, and *Stegomyia*, 157–189
Agathis, 17
australis, 17
palmerstoni, 28
robusta, 23, 27
vitiensis, 17
AKAMINE, ERNEST K.:
Germination of Seed of Koa Haole (*Leucaena glauca*), 51–52
Albizzia lophantha, 89
Alectron, 303
californiana, 306
catallus, 312
cerritensis, 308
cooperi, 309
cooperi var. *woodwardi*, 309
fossata, 304
insculptus, 312
insculptus eupleura, 312
mendica cooperi, 309
mendicus, 309
obsoleta, 314
pagoda, 310
perpinguis, 305
tegula, 307
versicolor, 310
algae, iodine in, 318
species tested for iodine, 319–323
Allometric Growth in the Striped Marlin, *Makaira mitsukurii*, from New Zealand, 53–58
Anomalopsylla, 86, 124
insignita, 85, 124
Anopheles, 151
farauti, 151, 152, 154
Alseuosmia macrophylla, 107
Anthomastus fisheri, 126
granulosus, 127
steenstrupi, 127
Arcularia, 303
major, 303
tegula, 307
tiarula, 307
Argyropelecus, 13

Aristotelia serrata, 100
Armigeres breinli, 151, 153, 154
Arytaina, 87, 91
robusta, 96
Asplenium nidus, 3
Atmetocranium, 86, 123
meyersi, 86, 123

BARNARD, J. LAURENS:
New Species of Amphipod from Lower California, 295–299
Bathytroctes rostratus, 14
BAYER, FREDERICK M.:
Descriptions and Redescriptions of Hawaiian Octocorals Collected by the "Albatross," 126–136
Boerhavia diffusa, 33
Boronia sp., 97
Brachyglottis repandra, 109
Buccinum
arcularia, 303
decussatum, 310
elegans, 304
fossatum, 304
papillosum, 303
tiarula, 307
Bulbophyllum, 3
Gibbonianum, 3
guamense, 4
micronesiacum, 3
nuruanum, 3
urceolatum, 4

Camphusia, 30, 31
glabra, 30
glabra kauaiensis, 30
Carmichaelia, 95
CARNAHAN, J. A.:
Inter-tidal Zonation at Rangitoto Island, New Zealand, 35–46
Cassinia leptophylla, 107
Cassis, 303
Chapmania sparmanella, 26
Christophersiomyia, 162
Clavularia corrugata, 131
expansa, 131
grandiflora, 129
ornata, 131
spiculicola, 131
Clianthus puniceus, 89
Clinocottus recalvus, 256–258
Clupea pallasii, 62
Ctenarytaina, 86, 96
clavata, 96
distincta, 96
eucalypti, 97
fuchsiae, 96
lulla, 96
pollicaris, 96
thysanura, 97
Culex annulirostris, 151, 152, 153, 154
impatibilis, 187

Dacrydium bidwillii, 120
biforme, 120, 121
DEMOND, JOAN:
Nassariidae of the West Coast of North America, 300–317
Dendrobium, 5
Adamsii, 5
carolinense, 6
coerulescens, 7
implicatum, 6, 7
lapeyrousioides, 7
nanarauticolum, 6
ponapense, 7
violaceo-miniatum, 7
patenti-filiforme, 6
pruinosum, 6, 7
Descriptions and Redescriptions of the Hawaiian Octocorals Collected by the U. S. Fish Commission Steamer "Albatross." (1. Alcyonacea, Stolonifera, and Telestacea.), 126–136
Dew as a Source of Plant Moisture, 259–261
Diplocaulobium, 7
carolinense, 7
elongaticolle, 8
flavicolle, 9
nitidissimum, 8
Discaria toumatou, 98, 99, 103
Dodonaea viscosa, 87, 93
Dracophyllum urvilleanum var. *montanum*, 118
DUMBLETON, L. J.:
A New Genus of Seed-infesting Micropterygid Moths, 17–29

earthquake, Kona, 269
damage, 273–281
epicenter, 284
instrumental data, 270
intensity, 285
tsunami, 274
Echinochloa colona, 151
Eione, 303
Eleusine indica, 151
Engraulis australis, 68
mordax, 62, 68
Epinnula, 193, 195, 198, 202
magistralis, 193, 198–200
Eriocrania purpurella, 26, 27
sangi, 26
Eriopisa, 295
chilkensis, 297
elongata, 297
garthi, 295
philippensis, 297
seurati, 297
Eriopisella, 297
capensis, 297
pusilla, 297
sechellensis, 297
Eucalyptus bicostata, 97
globulus, 97
Euphalerus nidifex, 87, 93

Fimbristylis atollensis, 145–150
cymosa, 149, 150

Galeodes, 303
Geissanthera, 9
Hosokawae, 9
papuana, 9, 10
Gempylus, 193, 195, 202
serpens, 197, 201–203
Geniostoma ligustrifolium, 98

Genus *Acer* (Maples) in Formosa and the Liukiu [Ryukyu] Islands, 288–294
Geoskusea, 162
Germination of Seed of Koa Haole (*Leucaena glauca*), 51–52
GILL, WILLIAM R., and G. D. SHERMAN:
Gray Hydromorphic Soils of Hawaiian Islands, 137–144
Gonostoma, 13
GOSLINE, WILLIAM A.:
A New Atherinid Fish of the Genus *Iso* from the Hawaiian Islands, 47–50
Gouania Hillebrandii, 255
GRIMM, MADELON R.:
Iodine Content of Some Marine Algae, 318–323
growth patterns of fish, 54
Gyropsylla, 86, 123
zealandica, 124

Hakea acicularis, 92
dactyloides, 92
HANEDA, YATA:
Some Luminous Fishes of the Genera *Yarrella* and *Polyipnus,* 13–16
HARTMAN, OLGA:
On the Identity of *Stylarioides inflata,* 71–74
HAWKES, ALEX D.:
Notes on a Collection of Orchids from Ponape, Caroline Islands, 3–12
Hebe angustifolia, 119
salicifolia, 85, 99, 101, 120
HIATT, ROBERT W., and A. L. TESTER:
Variation in the Vertebral Number of the Anchovy, 59–70
Hibiscus tiliaceus, 7
HULL, WILLIAM B., and KENNETH L. KNIGHT:
Aedes Mosquitoes of the Philippines. II., 157–189

iao, 47
Ilyanassa obsoleta, 314
Inter-tidal Zonation at Rangitoto Island, New Zealand. (Studies in Inter-tidal Zonation 4.), 35–46
Iodine Content of Some Marine Algae, 318–323
Isodendrion, 213
Fauriei, 255
Forbesii, 218–221
hawaiiense, 218, 221–224
Hillebrandii, 218, 224–226
Hosakae, 218, 226–229
lanaiense, 218, 229–232
laurifolium, 217, 232–234
longifolium, 217, 234–236
Lydgatei, 218, 236–239
maculatum, 218, 239–243
molokaiense, 218, 243–245
pyrifolium, 218, 245–247
Remyi, 218, 247–250
subsessilifolium, 218, 250–252
waianaeense, 218, 252–255
Iso flos-indicus, 49
flos-maris, 49
hawaiiensis, 47–49
natalensis, 49
rhothophilus, 49
Ipomoea pes-caprae, 33
IWAI, TAMOTSU, and KIYOMATSU MATSUBARA:
Studies on Japanese Gempylidae, 193–212

JUNE, FRED C.:
Observations on a Specimen of Bluefin Tuna, 75–76

Kauri, seed-infesting moths of, 17–29
KNIGHT, KENNETH L., and WILLIAM B. HULL:
Aedes Mosquitoes of the Philippines. II., 157–189
Kona Earthquake of August 21, 1951, and Its Aftershocks, 269–287

LAIRD, MARSHALL:
Mosquitoes of Nissan Island, 151–156
LEOPOLD, LUNA B.:
Dew as a Source of Plant Moisture, 259–261
Lepidocybium, 195
Leptospermum ericoides, 96
scoparium, 96
Leucaena glauca, 51
LEVI-CASTILLO, ROBERTO:
Redescription of *Aedes camposanus,* 262–264
Levidea lineata, 123
LI, HUI-LIN:
Genus *Acer* in Formosa and the Liukiu Islands, 288–294
littoral ecology, 35–46
luminous fish, 13

MACDONALD, GORDON A., and CHESTER K. WENTWORTH:
The Kona Earthquake of August 21, 1951, and Its Aftershocks, 269–287
Makaira albida, 56
mitsukurii, 53
nigricans ampla, 54
nigricans marlina, 56
MATSUBARA, KIYOMATSU, and TAMOTSU IWAI:
Studies on Japanese Gempylidae, 193–212
Maurolicus, 13
Metaphalara, 86, 123
zealandica, 123
Metrosideros excelsa, 122
umbellata, 102
Microtatorchis, 9
Micropterygoidea, 17
Micropteryx ammanella, 26
aureatella, 25
calthella, 25
Mimasea, 193, 195, 200, 202
taeniosoma, 194, 197, 200–202
Mnemonica auricyanea, 23, 26, 27
Moerenhoutia, 10
constricta, 10
lamellata, 10
leucantha, 10
Monograph of the Genus *Isodendrion* (Violaceae), 213–255
MORRIS, ROBERT W.:
Spawning Behavior of Cottid Fish, 256–258
MORROW, JAMES E., JR.:
Allometric Growth in the Striped Marlin, 53–58
mosquitoes, 151, 157
mud snails, 300
Mühlenbeckia australis, 118

Nassa californiana, 306
cerritensis, 308
cooperi, 309
corpulenta, 314
delosi, 306

fossata, 304
gibbsii, 309
insculpta, 312
intastriata, 305
interstriata, 305
mendica, 308
var. *cooperi*, 309
obsoleta, 314
pagoda, 310
perpinguis, 305
reevei, 304
tegula, 307
tiarula, 307
versicolor, 310
var. *striatula*, 310
Nassariidae, 300
ecology, 300
taxonomy, 302
Nassariidae of the West Coast of North America between Cape San Lucas, Lower California, and Cape Flattery, Washington, 300–317
Nassarius, 303
californianus, 304, 306
catallus, 304, 312
cerritensis, 304, 308
cooperi, 309
corpulentus, 304, 309
dentiferus, 315
eupleura, 312
fossatus, 304
insculptus, 304, 312
lirata, 316
mendicus, 304, 308
mendicus cooperi, 304, 309
mendicus indisputabilis, 316
nodicinctus, 315
nodiferus, 315
noduliferus, 315
obsoletus, 304, 314
onchodes, 316
pagodus, 304, 310
perpinguis, 304, 305, 307
tegula, 304, 307, 308
tegula tiarula, 304, 307
tiarulus, 307, 308
tschudii, 315
versicolor, 304, 310
Nealotus, 193, 195, 207
tripes, 207–209
nehu, 59
Neoepinnula, 193, 195, 202
orientalis, 193, 194, 196, 197, 200, 201
Neopseustis, 26
New Atherinid Fish of the Genus *Iso* from the Hawaiian Islands, 47–50
New Genus of Seed-infesting Micropterygid Moths, 17–29
New Species of Amphipod from Lower California (Genus *Eriopisa*), 295–299
New Variety of *Pandanus* and a New Species of *Fimbristylis* from the Central Pacific Islands, 145–150
Notes on a Collection of Orchids from Ponape, Caroline Islands, 3–12
Notes on Hawaiian Species of *Scaevola* (Goodeniaceae). Hawaiian Plant Studies 19, 30–34
Notes on the Mosquitoes of Nissan Island, Territory of New Guinea, 151–156
Nothofagus, 99, 119
Nothopanax, 99, 104
anomolum, 105
arboreum, 105
colensoi, 105
edgerleyi, 105
simplex, 105
Notocheirus, 49
hubbsi, 49

Oberonia, 10
Hosokawae, 10
ponapensis, 10
Observations on a Specimen of Bluefin Tuna (*Thunnus thynnus*) Taken in Hawaiian Waters, 75–76
Olearia, 85
arborescens, 112
avicenniae folia, 102, 111
ilicifolia, 110, 112, 114
lacunosa, 114, 115, 116
macrodonta, 112, 113
rani, 112
On the Identity of *Stylarioides inflata* (Treadwell) and Its Extended Distribution (Annelida), 71–74
On the Psyllidae of New Zealand (Homoptera), 83–125
orchids, 3

Pandanus odoratissimus var. *novocaledonicus*, 145
odoratissimus var. *novoguineensis*, 145
Papiana, 96
distincta, 96
lulla, 96
Parathunnus sibi, 76
Paspalum conjugatum, 151
Pauropsylla meyersi, 123
depressa, 123
verticis, 123
Pennisetum macrostachyum, 152
Phaius, 10
amboinensis, 10
Photichthys argentius, 14
Phreatia
caroliniensis, 10
Goodspeediana, 11
Kanehirae, 10
kusaiensis, 10
ladronica, 10, 11
pacifica, 10
palawensis, 10
pseudo-Thompsonii, 10
ponapensis, 10
Thompsonii, 10
Pittosporum, 98
colensoi, 98
crassifolium, 98
eugenioides, 98
tenuifolium, 98
Platycheirus, 110
Polyipnus, 13
spinosus, 13
stereope, 13
Porichthys, 13
Powellia, 97, 98
Pranesus insularum, 47
Promethichthys, 193, 195, 207
prometheus, 194, 197, 201, 207, 209

Properties of the Gray Hydromorphic Soils of the Hawaiian Islands, 137–144
Pseuderia, 12
frutex, 12
micronesiaca, 12
Pseudocladochonus mosaica, 131
versluysi, 131
Pseudopanax, 104
Psylla, 86, 87
acaciae, 87, 92, 93
acaciae-baileyanae, 87, 91
albizziae, 89
apicalis, 87, 93
carmichaeliae, 87, 94
carmichaeliae indistincta, 95
conspicua, 87
dodonaeae, 87, 92
exquisita, 90
hakeae, 91
jucunda, 89
uncatoides, 89

Redescription of *Aedes* (*Ochlerotatus*) *camposanus* Dyar (1918) as a Valid Species Found in the Coastal Plain of Ecuador, 262–264
Rexea, 193, 195, 203
solandri, 201, 204–207
Rhinocola, 96
aceris, 86
eucalypti, 96
fuchsiae, 96
Rhinoskusea, 163
Rhyacophila dorsalis, 28
Ruvettus, 195

Sabatinca barbarica, 25
incongruella, 25
ST. JOHN, HAROLD:
Monograph of the Genus *Isodendrion,* 213–255
A New Variety of *Pandanus* and a New Species of *Fimbristylis* from the Central Pacific Islands, 145–150
Notes on Hawaiian Species of *Scaevola,* 30–34
Scaevola, 30, 31
coriacea, 30
enantophylla, 31
frutescens, 32. 145
frutescens noomomiana, 33
frutescens sericea, 32
glabra, 30, 31, 32
Gaudichaudiana, 34
Helmsii, 31
Kauaiensis, 30
Menziesiana, 30
mollis, 33
mollis albiflora, 33
Skottsbergii, 30
tomentosa, 31
Schefflera, 106
digitata, 106
Schizopyga californiana, 306
californica, 306
Semicassis, 303
Senecio, 85
adamsii, 108
rotundifolius, 117
Shawia paniculata, 85, 102, 125
SHERMAN, G. DONALD, and WILLIAM R. GILL:
Gray Hydromorphic Soils of Hawaiian Islands, 137–144
Siphonogorgia alexanderi, 128
collaris, 129
variabilis, 129
Skusea, 157
soils, gray hydromorphic, 137
Some Luminous Fishes of the Genera *Yarrella* and *Polyipnus,* 13–16
Sophora tetraptera, 93
Spawning Behavior of the Cottid Fish *Clinocottus recalvus* (Greeley), 256
Stegomyia, 165
Sternoptyx, 13
Stolephorus purpureus, 59
Studies on Some Japanese Fishes of the Family Gempylidae, 193–212
Stylarioides inflata, 71–74
dimissus, 71

Taeniophyllum, 9
Tainarys, 86, 124
taro, 152
Telesto ambigua, 131
Telestula, 131
corrugata, 133
septentrionalis, 131
spiculicola, 131
spiculicola robusta, 133
TESTER, ALBERT L., and ROBERT W. HIATT:
Variation in the Vertebral Number of the Anchovy, 59–70
Tetragonocephala flava, 93
Thunnus orientalis, 75, 76
thynnus, 75, 76
tidal factors in littoral ecology, 40–44
Trioza, 86, 97
acuta, 107, 108
adventicia, 98, 121
alseuosmiae, 106
australis, 116, 117
bifida, 102, 105
colorata, 120
compressa, 111, 112
crinita, 112, 113, 114
curta, 122
dacrydii, 120
decurvata, 118
discariae, 98, 103
doryphora, 109, 110, 112
emarginata, 99
equalis, 100
eugeniae, 122
falcata, 100
fasciata, 117
flavida, 115, 116
gourlayi, 102
hebicola, 85, 99, 101
irregularis, 104, 105, 106
latiforceps, 114, 115, 116
obfusca, 118
obscura, 118
panacis, 103, 105
parvipennis, 107
schefflericola, 106
scobina, 114, 115
styligera, 117
subacuta, 108, 111, 112

subvexa, 105, 110, 112
vitreoradiata, 98, 99, 105
Tripteroides nissanensis, 151, 154
quasiornatus, 154
Triton pagodus, 310
Trophonia inflata, 71
minuta, 71
Tropidostethops, 49
tsunami, 274
TUTHILL, L. D.:
On the Psyllidae of New Zealand, 83–125

Variation in the Vertebral Number of the Anchovy (*Stolephorus purpureus*) in Hawaiian Waters, 59–70
vertebral number in anchovies, 59

Weinmannia racemosa, 123
sylvicola, 123
WENTWORTH, CHESTER K., and GORDON A. MACDONALD:
The Kona Earthquake of August 21, 1951, and Its Aftershocks, 269–287
Wuchereria bancrofti, 154

Yarrella, 13
blackfordi elongata, 13
blackfordi illustrius, 13

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